UNCLASSIFIED

Research on Building Education & Workforce Capacity in Systems Engineering

Final Technical Report SERC-2011-TR-008-3

October 31, 2011

Principal Investigator: Elisabeth McGrath, Senior Research Associate & Executive Director Center for Innovation in Engineering & Science Education (CIESE) (Stevens Institute of Technology)

Team Members

Dr. Mark Ardis (Stevens Institute of Technology)

Christian Jurado, Research Associate (Stevens Institute of Technology

Dr. Susan Lowes, Director, Research and Evaluation, Institute for Learning Technologies, (Teachers College/Columbia University)

Sophie Lam, Research Assistant, Institute for Learning Technologies

Contract Number: H98230-08-D-0171 DO1, TTO2, RT019

Report No. SERC-2011-TR-008-3
October 31, 2011

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **31 OCT 2011**	2. REPORT TYPE	3. DATES COVERED **00-00-2011 to 00-00-2011**

4. TITLE AND SUBTITLE **Research on Building Education & Workforce Capacity in Systems Engineering**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Systems Engineering Research Center,Stevens Institute of Technology ,1 Castle Point on Hudson,Hoboken,NJ,07030**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**109**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

This material is based upon work supported, in whole or in part, by the U.S. Department of Defense through the Systems Engineering Research Center (SERC) under Contract H98230-08-D-0171. SERC is a federally funded University Affiliated Research Center managed by Stevens Institute of Technology

Table of Contents

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

RT-19, *Research on Building Education & Workforce Capacity in Systems Engineering*, is a research study whose goal is to understand the impact on student learning of and career interest in Systems Engineering (SE) through a set of diverse capstone courses that expose students to authentic Department of Defense (DoD) problems and engage them in learning and practice of systems engineering. SE Capstone courses were developed and piloted during the 2010-11 academic year (and beyond) in eight civilian universities and six military institutions affiliated with the Systems Engineering Research Center (SERC). The strategic goal addressed by this research is to better understand how differing course designs, structures, materials, instructional practices, and other inputs, such as the involvement of DoD and industry mentors, impact student learning and career interest in SE. This research explored methods and approaches to augment the SE workforce for future DoD and related industry workforce needs in order to inform future investments for the purpose of institutionalizing and scaling up effective methods. This research encompassed a 20-month, three-phase effort from March 1, 2010 to October 31, 2011, including planning, course implementation, and analysis. Institutions were selected for participation through a competitive application process based on a set of criteria developed in consultation with the sponsor, and partners were awarded a subcontract of approximately $200,000 for development, implementation, analysis, and reporting on their SE Capstone project.

According to final reports submitted by principal investigators, 330 and 257 students participated in RT-19-sponsored SE Capstone courses in the fall 2010 and spring 2011 semesters, respectively. Many institutions enrolled the same students for both semesters, but a few, such as the University of Maryland, enrolled a new cohort of students in the spring, bringing the total number of students impacted to more than 360. Approximately half were undergraduates, of whom the majority were fourth year seniors. Of the graduate students, most were first year students, with small percentage post-graduates participating in roles such as project manager.

Four topic areas illustrating authentic DoD problems were presented for student teams' projects. Problem area #1, low-cost, low-power computer solutions (see Table 2 for more complete description), was the most heavily subscribed topic, with more than half the projects addressing this problem area. Problem areas were selected, in part, based on expertise of participating faculty and institutional resources, and on availability of DoD and local experts. Institutions organized their teams in different ways: the most common structure included several teams working on several different design problems.

A majority of the universities relied on the expertise of systems engineering faculty to lead or contribute to the conceptualization, development, and implementation of the course, but many other faculty were

involved as well, particularly from mechanical engineering and computer science departments. At 11 institutions, faculty came from at least three separate engineering disciplines, literally embodying the multi-disciplinarity of an SE team. Nearly two-thirds of the 14 projects were planned and implemented by teams of two or three faculty members, but four projects included four or more faculty. Only one institution (US Naval Academy) developed a Capstone course that was planned and taught by a single faculty member.

The research team gathered the following data in order to analyze the impact of the SE Capstone project on student learning of SE, student interest in SE careers, and student awareness/interest in authentic DoD problems: pre/post student surveys; pre/post case study analysis by students; and student blog posts. In addition, this report also contains input gathered from the July SE Capstone conference, review and analysis of final reports submitted by principal investigators, as well as papers, publications, and posters developed by faculty, researchers, and students.

Many faculty used customized assessments and other means (e.g., student participation in competitions) to assess student outcomes (See Appendix B for description of course materials/student deliverables and internal assessments). Through semantic analysis of students' constructed responses on definitions of systems engineering (administered in pre- and post-course surveys) as compared to two expert definitions, larger gains were observed for undergraduates and students with no prior SE experience than for students who self-identified with prior SE knowledge. Students with no prior SE experience not only showed larger gains, but also they ended with a slightly higher percentage than the group as a whole.

The research team used an analytic rubric to measure changes in the level of complexity of student thinking using systems engineering knowledge from pre- to post-course on the case study analysis of the Bradley Fighting Vehicle. A life cycle model was used to map units of competency from the SPRDE-SE/PSE Competency Model into lower (definitional) or higher (development, deployment) categories of analysis (Sage, 2000, p. 166). For the entire set of matched responses, statistically significant increases were recorded for all categories of competencies combined, and for categories B and C (denoting more sophisticated reasoning). Students with prior SE experience had higher initial and final scores, but the difference between the two groups' (students with and without prior SE experience) was smaller by the post-test, suggesting that the SE Capstone courses positively impacted student learning of SE, particularly for those students without SE experience. The increases were statistically significant for both groups of students.

Finally, weekly posts to weblogs ("blogs") and a final post were required of all teams in order to provide qualitative data and insights into the changes in the level of complexity of students' thinking about SE as applied to their Capstone project. Blogs were used in a variety of ways by partner institutions; therefore, generalizations about the RT-19 student population cannot be made from this data source. Student blog posts described phases of the SE design process; included project artifacts and media files; and described challenges teams encountered during the project. These included such issues as making design tradeoffs; providing adequate security for their (wireless) products; relying too much on knowledge or technical skills of one team member with a specific area of expertise; setting reasonable and achievable goals for product design within a school year; communication challenges in an interdisciplinary team with different perspectives and varying levels of expertise; and managing time

and design constraints. The most common student responses about the most challenging aspects of the project included managing the dynamics of a multi-disciplinary group and communication problems.

Overall, 82% of responding students felt their group produced a successful product. Of those who did not feel their projects were successful, lack of resources and time were the most frequently cited reasons.

A goal of the SE Capstone courses implemented in RT-19 was to increase student awareness of the diversity of problems addressed by the DoD. From pre- to post-survey, changes from very general to more specific types of problems identified by students, including greater use of SE terminology, were observed. The problem area that increased the most in students' awareness was energy-related, particularly energy efficiency and green energy, while the area that decreased the most was weapons and weapon systems.

Another goal of SE Capstone courses was to increase student interest in: SE careers generally; SE careers in government; and SE careers in industry. Post-survey means for the entire population of matched pre-/post-survey responses increased in all three categories, although these increases were not statistically significant. For those students with prior SE experience, Q1 (general) and Q3 (industry) increased, while the mean for Q2 (government) decreased. For the matched group without prior SE experience, the means for all three questions increased, with the mean for Q3 (industry) increasing the most. Further analysis of students' Likert Scale responses show more subtle differences in the level of interest (from low to high) among the various subgroups analyzed. Eighty percent of students who responded to an open-ended question asking whether they would pursue a career in systems engineering career and, if so, why, stated that they would, and many indicated this would be some time in the future after gaining experience in their chosen engineering discipline. The remaining 20 percent who responded they would not consider a career in SE listed a preference for pursuing their chosen engineering career as the main reason. Overall, a large majority of students who answered an open-ended question about the applicability of systems engineering to future engineering studies and plans (64 of 67) agreed that SE provided a useful framework and broad perspective needed to manage complex engineering challenges.

The recruitment, involvement, and impact of DoD and industry mentors is an aspect of the SE Capstone project which deserves special emphasis in the analysis of the overall project in light of the intensive efforts made to connect mentors with student teams, the voluntary nature of mentors' roles, and implications for sustainability and scaling up. All Capstone partner institutions had a DoD mentor, and about half had additional mentors. Mentors played the role of clients as well as technical experts, guiding students toward solutions. Lack of role definition of mentors was cited as problematic by PIs; preference was expressed for DoD mentors to serve as clients. Lack of and late start of mentor involvement with student teams, as well as varying levels and frequency of communication between mentors and students were cited as challenges. Beneficial impacts of mentor involvement were reported by PIs when communication was frequent and specific, particularly in the case of design reviews. Defense prime contractors who served as mentors were reported to provide a different perspective than DoD mentors, chiefly, by representing "the solution viewpoint" and "saving student teams from exploring too many blind alleys." Student rankings of DoD and industry mentors' usefulness in learning about and applying SE in their courses were in the mid- to low range for all but one

institution, as compared to six other course inputs such as lectures and other team members. In considering sustaining mentor relationships and scaling up, it will be important to examine value of mentors, the sustainable features of mentor relationships, and the characteristics of particularly strong mentor relationships.

Through site visits to SE Capstone universities in spring 2011, a team of sponsor representatives identified a set of promising practices—approaches which were present in universities where students demonstrated higher levels of communication, analysis, and awareness of the SE process during the site visits. Although limitations of the data and the scope of RT-19 do not allow for analysis of correlations between these promising practices and the SE Capstone models that may have led to greater student outcomes, these promising practices have informed the research being undertaken through RT-19A, the *Pilot for Scaling Up and Sustaining Effective SE Capstone Practices*. A graphical representation of the presence (or lack thereof) of these promising practices among all participating RT-19 universities appears as Appendix E.

In order to institutionalize aspects of the SE Capstone project post-DoD funding, it will be necessary to address the critical challenges faced by faculty who are responsible for implementing these projects. Some challenges identified by faculty resulted from the accelerated startup and logistical demands associated with a new course. Here, issues such as recruitment, material and assessment development, coordination of schedules among students in different engineering disciplines and coordination with external mentors were commonly cited challenges. Other challenges were associated with establishing a broad, overarching SE framework in the context of traditional departmental academic structures. Course expectations, grading policies, and formation of teams representing different disciplines were cited as issues, as were negotiating the optimal balance between SE content knowledge and discipline-specific technical expertise among students and faculty and identifying manageable project scope for the given instructional period. Lastly, models for sustaining and institutionalizing SE Capstone projects were proposed, including fee-based programs in which students work on a problem from industry or government as a contractor.

Findings and Recommendations:

Limitations in the data and the many approaches and variables used in the 14 pilot courses prevent statistical correlations with student outcomes and “optimal” course designs. However, the following summary of findings are grounded in data collected through RT-19:

Analysis of student definitions of systems engineering showed that participating students were able to use general systems engineering terminology almost as well as experts but that they still had some way to go in employing more technical systems engineering language. However, those with the most to learn—undergraduates and those with no prior system engineering experience—improved the most, particularly in terms of technical language.

Analysis of the Bradley Fighting Vehicle case study showed that students increased in their ability to identify problems that mapped to specific systems engineering competencies, particularly those related to the technical elements, but that they were less likely to mention the “soft” competencies like communication and leadership.

The blogs, where used well, showed students working through the phases of the design process and struggling with various technical and communication issues along the way.

Students enjoyed the real-world nature of the projects—both in terms of building an artifact that might be used and in terms of the SE project context (budget constraints, interdisciplinary teams, experts as mentor)—and that they appreciated the contribution that the systems engineering perspective brought to their work.

SE Capstone courses do not appear to have had a major impact on the students' immediate career plans, it must be noted that many had their immediate post-college plans in place and that a large majority of both undergraduates and graduate students believed that they might choose careers in systems engineering sometime in the future.

Recommendations for future implementations and future research include:

1. Develop a methodology to prioritize and rank the student attributes and outcomes most likely to meet DoD and defense industry needs in the near term (0-5 years) and longer term.
2. Examine the presence, depth, and characteristics of implementation of the promising practices through case study analysis (a component of research included in RT-19A); correlate, where possible, to the highest priority student attributes described in (1), above.
3. Distill the attributes of effective DoD and industry mentor relationships through further analysis of "what worked" and what did not. Investigate the incentives and rewards for mentors to continue involvement with university partners.
4. Make very explicit the goal of attracting students to DoD careers in systems engineering in coursework and other communications; provide technical assistance and other materials to mentors and faculty.
5. Leverage the experience and expertise of the RT-19 and RT-19A to build and expand a learning community of SE Capstone stakeholders (engineering institutions, clients, and mentors).
6. Consider piloting new approaches to sustain the SE Capstone project, including the creation of an online repository of potential DoD problem areas and clients along with a "venture fund" that would provide small grants of $5,000-$10,000 for materials and access to DoD problems and clients for institutions that already organize Capstone projects.
7. Publicize in relevant professional journals, education media, and the general media the contributions of SE Capstone design teams to the development of solutions critical for our military and our nation's security.
8. Conduct a longer-term study (1-5 years) tracking RT-19 participants and their career choices and employment trends.

1.0 INTRODUCTION

1.1 PROJECT OVERVIEW

A 45% growth is expected in SE jobs in the next decade and there have been numerous studies and workshops that have highlighted the shortfalls in both the number and capability of the SE workforce (Rosato, Braverman, & Jeffries, 2009). The July 2006 National Defense Industrial Association (NDIA) Task Force noted among the top five SE issues the lack of adequate, qualified SE human capital resources within government and industry for allocation on major programs (National Defense Industrial Association SE Division Task Group , 2006). In the July 2010 NDIA white paper on critical SE challenges, Issue 2 was identified as: *The quantity and quality of SE expertise is insufficient to meet the demands of the government and defense industry*, and further outlined certain recommendations to build SE expertise and capacity. In particular, it recommended developing SE expertise through "role definition, selection, training, career incentives, and broadening 'systems thinking' into other disciplines," and made a number of specific recommendations, including adding an introductory course in SE in all undergraduate engineering and technical management degree programs; and working with major universities to recommend SE curricula to improve consistency across programs in order to achieve standardization of skill sets for graduates (National Defense Industrial Association SE Division, 2010). With these industry-wide workforce demands challenging the systems engineering community, RT-19 was conceptualized and designed to pilot and evaluate approaches to ameliorating these shortages.

1.2 RESEARCH OBJECTIVES AND PROGRAM GOALS

Research on Building Education & Workforce Capacity in Systems Engineering, (referred to as the SE Capstone Project), aims to understand the methods through which SE learning and career interest may be increased among undergraduate and graduate engineering students. The key research question this program was designed to address is:

What organization of course work (course sequence, course materials, faculty characteristics, student characteristics and other inputs and activities) leads to the largest student gains in (1) SE learning; (2) interest in SE careers; and (3) interest in DoD problems and careers?

This research was conducted in the context of 14 "capstone" courses, in most cases as an integrative culminating, project-based course involving teams of students working together on the development of a product or prototype that addresses a real DoD need. Implemented as pilot courses in eight civilian and six military universities affiliated with the Systems Engineering Research Center, these 14 institutions piloted methods, materials, and approaches to create new courses or enhance existing courses to embed, infuse, and augment SE knowledge, as defined by the Systems Planning, Research Development, and Engineering (SPRDE)-SE and Program Systems Engineer (PSE) competency model, known as the SPRDE-SE/PSE Competency Model (Table 1), among undergraduate and graduate students. Participating university faculty developed new course materials and other methods and strategies to recruit and provide substantive SE learning experiences; increase exposure to authentic DoD problems, such as low-cost, low-power computing devices, expeditionary assistance kits, expeditionary housing systems, and immersive training technologies.

This pilot program was conducted in order to inform the development of a national scale-up effort that would substantially expand the number and capabilities of universities that could produce SE graduates needed for the DoD and related defense industry workforce. It was anticipated a portfolio of shareable course materials, assessment instruments, and other lessons would be produced in order to accelerate the adoption of effective practices and materials in a national scale up. Analysis of student data from several sources, PI reports, input from sponsors' site visit teams, and insights gleaned from panels and presentations at a culminating workshop form the basis for the content of this final report and recommendations.

Analytical (13)	1. Technical Basis for Cost
	2. Modeling and Simulation
	3. Safety Assurance
	4. Stakeholder Requirements Definition (Requirements Development)
	5. Requirements Analysis (Logical Analysis)
	6. Architectural Design (Design Solution)
	7. Implementation
	8. Integration
	9. Verification
	10. Validation
	11. Transition
	12. System Assurance
	13. Reliability, Availability, and Maintainability
Technical Management (12)	14. Decision Analysis
	15. Technical Planning
	16. Technical Assessment
	17. Configuration Management
	18. Requirements Management
	19. Risk Management
	20. Technical Data Management
	21. Interface Management
	22. Software Engineering
	23. Acquisition
	24. Systems Engineering Leadership
	25. System of Systems
Professional (4)	26. Communications
	27. Problem Solving
	28. Strategic Thinking
	29. Professional Ethics

Table 1: SPRDE-SE/PSE Competency Model

The 14 pilot universities were required to address one or more of four DoD problem areas and to produce an actual product, prototype, or other artifact to demonstrate their learning.

DoD Problem Areas
1. Low-cost, low-power computers leveraging open-source technologies and advanced security to support sustainable, secure collaboration; Portable, renewable power generation, storage, and distribution to support sustained operations in austere environments and reduce dependency on carbon-based energy sources; Portable, low-power water purification; 2. An expeditionary assistance kit around low-cost, efficient, and sustainable prototypes such as solar cookers, small and transportable shelters, deployable information and communication technologies, water purifiers, and renewable energies. These materials would be packaged in mission-specific HA/DR kits for partner nation use; 3. Develop modular, scalable, expeditionary housing systems that possess "green" electric power and water generation, waste and wastewater disposal, hygiene, and food service capabilities. Systems should be designed to blend in to natural/native surroundings and with minimal footprint; 4. Continued investigation and exploration into the realm of the possible with respect to "Immersive" training technologies. Objective is to flood the training audience environment with the same STIMULI that one would experience during actual mission execution. Where possible full sensory overload is desired much the same as experienced in combat. Specific S&T areas for development *Virtual Human.* Successful modeling of emotions, speech patterns, cultural behaviors, dialogue and gestures. *Universal Language Model.* The ability for trainees to seamlessly converse with the Virtual Human. *Virtual Character Grab Controls.* The ability for exercise controllers to assume control of virtual characters. *Automated Programming.* Cognitive learning models and the ability for exercise controllers to adjust virtual/live simulations. Low Cost wireless personnel sensors. *Sensors* (i.e., lightweight vests) that facilitate physical stimuli (i.e., wounds, shots) to trainees.

Table 2: DoD Problem Areas

1.3 RESEARCH QUESTIONS AND METHODS

Methodology: Measurement of Student Educational Outcomes

The impact of the variety of SE Capstone courses on the student outcomes identified above was designed to be measured through the administration of three "common" assessments, or assessments required of all SE Capstone student participants. These were designed to be administered at the beginning (pre-) and end (post-) of their Capstone course experience. These included:

1. *Pre/Post Survey*, focused on student knowledge of systems engineering, interest in systems engineering careers, and awareness of DoD problem areas.
2. *Pre/Post Case Study Analysis* [Bradley Fighting Vehicle], a semantic analysis designed to capture growth in SE approach/analysis
3. *Student Blogs* were intended to provide qualitative evidence of the progress in level of sophistication of student analysis.

Also, faculty of each participating institution developed customized assessments that were unique to their courses using diverse instruments such as those listed below:

- Comprehensive Rubrics
- Student Presentations/Briefings for design reviews and Final Project Presentation
- Peer Review
- Team Reports

A chart delineating the various internal assessments used by each partner university appears as Appendix B.

1.4 PARTICIPATING INSTITUTIONS AND SELECTION CRITERIA

A request for proposals was issued and a competitive application process was conducted in order to select SE Capstone partner institutions. An independent panel of SE and engineering education experts used a common scoring rubric to evaluate 11 proposals, which resulted in the selection of eight civilian institutions, which appear in Table 3. A separate process managed by the Office of the Assistant Secretary of Defense for Research and Engineering (ASDR&E) resulted in the participation of four service academies working under the direction of the Naval Postgraduate School and Air Force Institute of Technology, bringing the total number to 14 partner institutions.

Partners

Civilian Universities
1. Auburn University
2. Missouri University S & T
3. Penn State
4. Southern Methodist University
5. Stevens Institute of Technology
6. University of Maryland
7. University of Virginia
8. Wayne State

Service Academies
1. Air Force Institute of Technology
2. Naval Postgraduate School
3. Air Force Academy
4. Military Academy – West Point
5. Coast Guard Academy
6. Naval Academy

Table 3: Partner Institutions

1.5 TIMELINE

The following is a brief description of the three phases of the RT19 project:

Phase 1/Startup (March 1, 2010-May 15, 2010) was accelerated in order to provide program requirements and executed subcontracts to enable partner universities to develop materials and conduct program implementation in the Fall 2010 academic semester. Two universities conducted one-semester Capstone courses; 11 conducted two-semester courses; and one (NPS) organized its Capstone course over multiple terms.

Phase 2/Pilot Implementation (May 15, 2010-June 30, 2011) Capstone institutions developed course materials and assessment instruments (July-September 2010); delivered the courses (August 2010-May 2011); and submitted two interim reports (July 2010 and January 2011) and a final report (June 2011). Some variation in this schedule was based on the specific calendar for classes at each Capstone Team member.

Phase 3/Analysis, Recommendations & Dissemination (July 1, 2011 – October 31, 2011) This phase coordinated a summative workshop for all RT-19 and RT-19A (the follow-on research) constituents, and conducted/compiled the analysis of results of student assessments and other data and artifacts for submission in a final report.
The following figure shows the milestones of each phase:

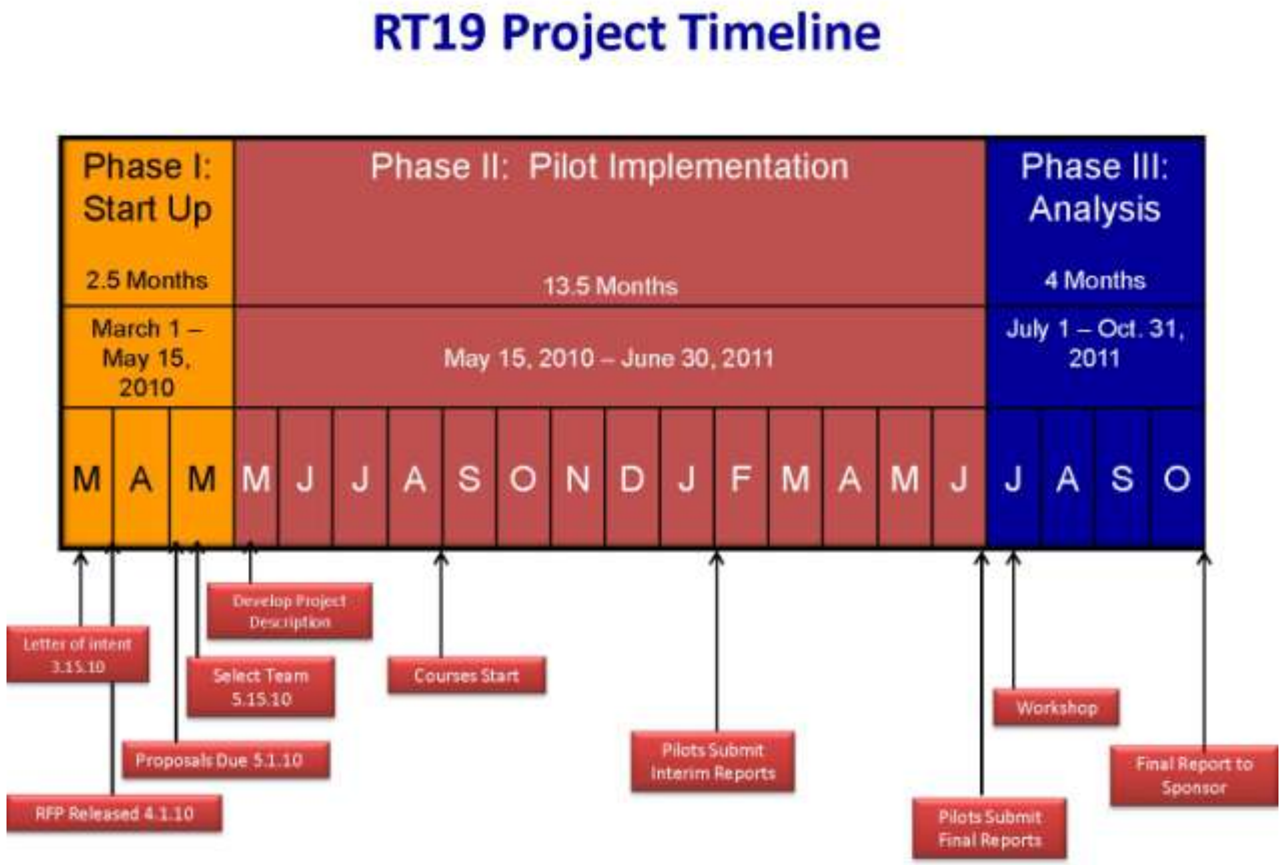

Figure 1: RT19 Project Timeline

1.6 SUMMARY OF PARTICIPANTS IMPACTED

According to final reports submitted by principal investigators, 330 and 257 students participated in RT-19-sponsored SE Capstone courses in the fall 2010 and spring 2011 semesters, respectively. Many institutions enrolled the same students for both semesters, but a few, such as the University of Maryland, enrolled a new cohort of students in the spring, bringing the total number of students impacted to more than 360. Approximately half were undergraduates, of whom the majority were fourth year seniors. Of the graduate students, most were first year students, with small percentage post-graduates participating in roles such as project manager.

While the total number of undergraduates and graduate students was nearly equal across the 13 institutions, a closer look at differences between individual institutions shows that nearly half of the 13 institutions (Penn State, UVA, SMU, CGA, AFA, and West Point) were comprised entirely of undergraduates. Four institutions (Wayne State, AFIT, NPS, and the Naval Academy) enrolled graduate students (including postgraduate students) and the remaining three (Auburn, Missouri S&T, and Stevens) enrolled both undergraduate and graduate students. However, the ratio varied:

while Auburn had mostly graduate and postgraduate students (92 percent), with fairly few undergraduates, Stevens had a 2:3 ratio of undergraduates to graduate students, and Missouri S&T had a 1:4 ratio.

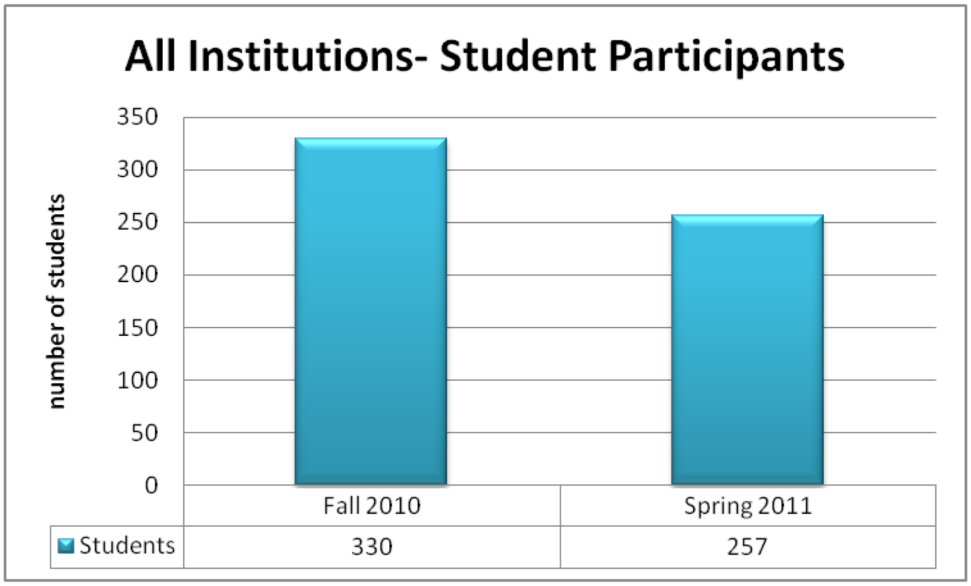

Figure 2: All Institutions – Student Participants

1.7 FACULTY INVOLVEMENT

According to original proposals and project reports, approximately 50 faculty participated in the development, delivery, and/or assessment of the SE Capstone courses across the 14 participating institutions. A majority of the universities relied on the expertise of systems engineering faculty to lead or contribute to the conceptualization, development, and implementation of the program, but many other faculty were involved as well, particularly from mechanical engineering and computer science. At 11 institutions, faculty came from at least three separate engineering disciplines, literally embodying the multi-disciplinary character of a systems engineering team. In the following graph, percentages represent the percentage of the 14 pilot universities that included those types of disciplinary faculty in the RT-19 project.

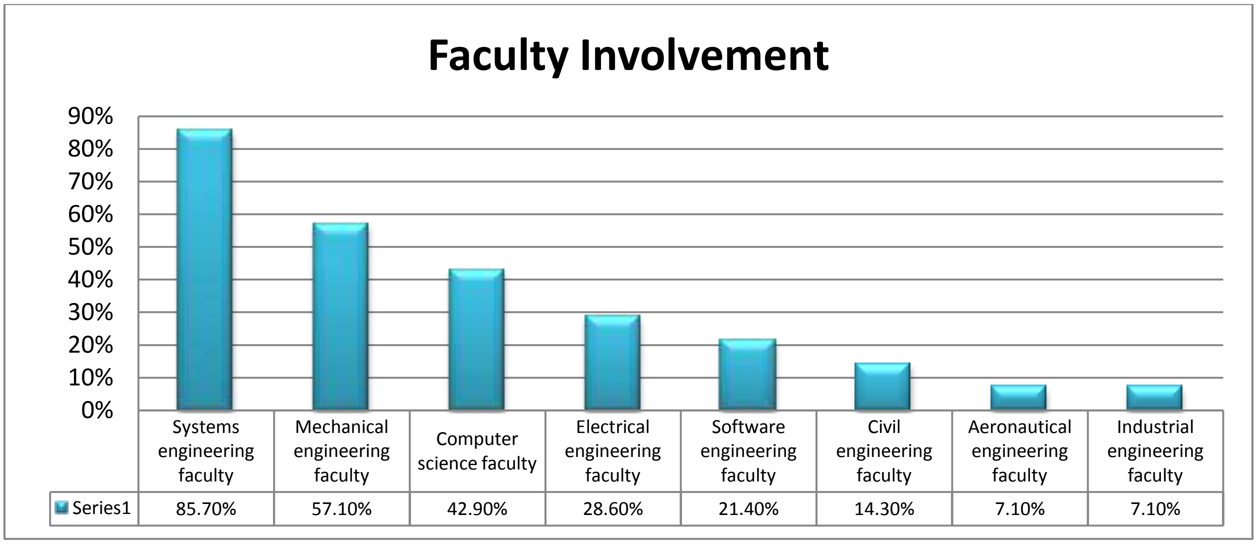

Figure 3: Faculty Involvement

Nearly two-thirds of the fourteen projects were planned and implemented by teams of two or three faculty members, but four projects included four or more faculty. Only one institution developed a capstone course that was planned and taught by a single faculty member

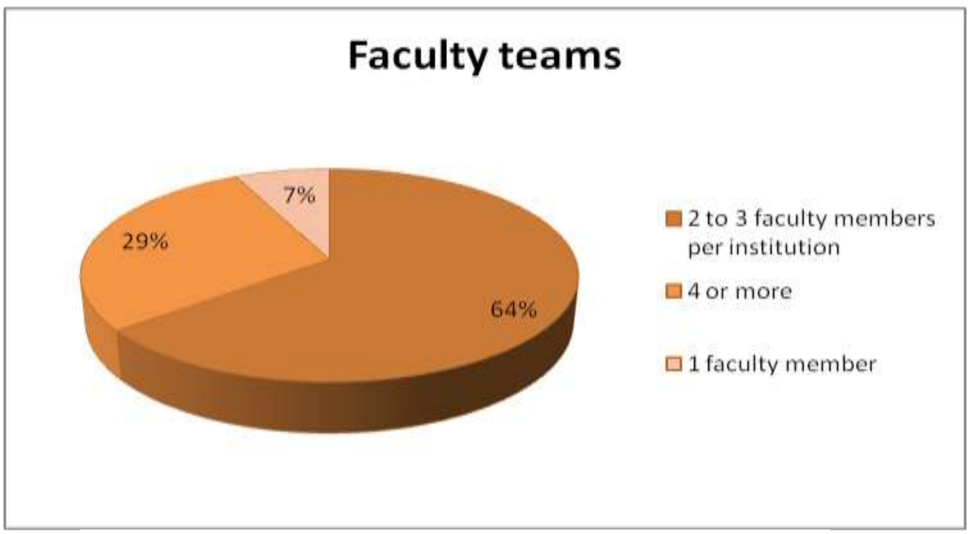

Figure 4: Faculty Teams

1.8 DOD/INDUSTRY MENTORS

Approximately 30 DoD and industry mentors contributed to the SE Capstone projects. In many cases, mentors were recruited from the project kickoff meeting in August 2010, while in others, institutions

tapped their own networks to recruit mentors. In some institutions mentors played multiple roles, including as client and as technical advisor.

PI reports included the following mentor contacts:

University/Academy	Mentors
Auburn	Advisory board (5 SE professionals from govt. and industry) Industry Mentor (automotive arena) PhD TAs (support team)
Missouri S&T	Boeing company engineers: Dale Waldo, Louis Pape, Nancy Pendleton, Robert Simmons and Robert Scheurer Office of Naval Research: Pete Muller
Penn State	DoD Mentors: Col. Nancy Grandy, and Mr. Phil Stockdale
Southern Methodist	U.S. Marine Corps Office of Naval Research: Pete Muller
Stevens Institute	Naval Surface Warfare Center: Eric Shields Red Gate Group, Ltd: Joseph Barniak
U of Maryland	Lockheed Martin: Sandy Friedenthal DoD Mentors: Dr. David Robie, Kim Watkins
U of Virginia	DoD Mentor: Bill Campbell Northrop Grumman engineers
Wayne State	Army Shelter Expert: Claudia Quigley Army TARDEC: Dr. Pete Schil
Military Academy	SRI/Sarnoff: Dr. Rakesh Kumar DoD Mentors: LTC Joe Nolan, LTC Chris Vaughn [Joint Advanced Training Technologies Lab]
Air Force Academy	DoD Mentors: a reserve AF Colonel, a retired USMC officer

Table 4: Mentors

Eight civilian universities and two service academies reported working with mentors as shown in the table above.

2.0 ANALYSIS OF SYSTEMS ENGINEERING STUDENT LEARNING OUTCOMES

RT-19-sponsored SE Capstone courses were designed to increase student:

- Understanding of the discipline of systems engineering
- Understanding of the work of systems engineers
- Facility and practice of SE knowledge and skills
- Interest in SE careers generally and in government and industry
- Knowledge of DoD problem areas related to SE

A mix of methods was used to assess the success of the SE Capstone courses in meeting these objectives. These included closed- and open-ended questions on pre- and post-surveys that included questions about understanding of systems engineering and career awareness, a case study, and weekly blog assignments. The case study, administered at the beginning of the first semester and again at the end of the year, was designed to assess students' level of sophistication in applying systems engineering thinking to a problem, while the weekly blogs were designed to provide a insights into how the students were developing specific systems engineering competencies.

2.1 STUDENT SURVEYS

Of the 14 schools that received RT-19 funding, a total of 301 students from 13 schools responded to the RT-19 pre-survey that was designed to assess student understanding of systems engineering, awareness of systems engineering careers, and interest in those careers. Students from 12 of those 13 schools completed the pre-survey in September 2010; students at one school (UMD) completed it in March 2011.

A total of 123 students from 12 schools completed the post-survey, although not all at the same time and not all to the same survey. Students from 10 schools responded to the full post-survey between May and June 2011. Students from Penn State University, who completed a one-semester course in the fall, responded to a post-survey that did not have two questions that were added subsequently. Students from UMD responded to the pre-survey twice, with the results that they did not respond to questions that were only on the post-survey. Finally, there were no responses from NPS, which was not due to complete the course until fall 2011, nor from Wayne State, which did not respond to multiple prompts from the research team regarding completion of the mandatory, common assessments.

Overall, the total post-survey responses (n=123) were 41% of the original pre-surveys (n=301) and the matched surveys (n=93) were 31%. However, since NPS was not expected to finish until Fall 2011, they should not be considered as part of the population. If NPS is removed, the total post-survey responses were 50% of the pre-survey responses and the number of matched pre-post survey responses was 76% of the post-survey responses.

The reduction, and lack of a larger match, was in part due to the fact that some students who took the first-semester course did not go on to the second semester, while at a few schools, new students joined.

For example, SMU had students in three fall semester capstone courses with 75 students total. Although 43 responded to the pre-survey, only 11 worked on DoD projects (according to the PI's report) and went on to the spring semester. At Auburn, only 15 of the original 33 went on to the second semester.

The table below compares the number of students in each semester, as reported by the PIs in their reports, the number of surveys received, and the number that could be matched pre-to-post:

	# Students Semester 1	# Pre-survey responses	# Students Semester 2	# Post-survey responses	# Matched Responses
AFA	7	10	7	6	6
AFIT	5	3	5 (1 student from first semester left; 1 student joined)	3	3
Auburn	33	41	17 (15 were from first semester)	14	7
CGA	20	14	24 (4 joined in spring)	17	11
MUST	30	20	30	17	13
NPS	38	57	38	0 (to come fall 2011)	0
PSU	17	17	17	15	13
SMU	75	43	11	7	2
Stevens	24	24	19 (5 graduate students left in spring)	9	9
UMD	15	35 (March 2011)	37	14	12
UVA	17	17	16	14	13
Wayne	29	16	16 (all new)*	0	0
USMA	4	4	4	4	4

USNA	16	0	16	3	0
Total	330	301	257	123	93
Total without NPS	292	244	219	123	93

Table 5: Administered Surveys

∗ The pre-surveys were collected from three classes of students in the fall semester. In the spring semester, one of these classes was repeated with a wholly new set of students who were not asked to complete the pre-survey. In addition, as noted above, no Wayne State students completed the post-survey.

2.2 CASE STUDY ANALYSIS: BRADLEY FIGHTING VEHICLE

A total of 158 students from 13 of the 14 institutions responded to the RT-19 Bradley Fighting Vehicle pre-course scenario prompt (the exception was NPS) and 97 students from 12 institutions responded to the post-scenario prompt. Wayne State and NPS, which will not complete the capstone course until fall 2011, did not respond to the post-scenario response.

There were 55 matched responses. Without NPS, this is 35% of the original pre-course case study group and 57% of post-course case study group:

	# Students Semester 1	# Pre-scenario responses	# Students Semester 2	# Post-scenario responses	# Matched Responses
AFA	7	8	7	6	3
AFIT	5	3	5	1	1
Auburn	33	31	17	13	6
CGA	20	2	24	13	1
MUST	30	1	30	6	0
NPS	38	0	38	0	0
PSU	17	17	17	15	15
SMU	75	10	11	7	6
Stevens	24	21	19	8	6
UMD	15	32	37	10	7
UVA	17	16	16	13	5
Wayne	29	10	16	0	0

USMA	4	4	4	4	4
USNA	16	3	16	1	1
Total	330	158	257	97	55
Total without NPS	292	158	219	97	55

Table 6: Administered BFV Case Study

In this report, two data sets – all post-survey responses and the smaller set of matched pre-post survey responses – were analyzed depending on the survey question.[1] Thus the entire set of responses was used for those questions that were only on the post-survey; for all other questions, the matched set was used.

Demographics of the Matched Set of Students.

Only 26 of the matched pre-post survey population (n=93) were Systems Engineering majors. The majority (n=67) were other primarily engineering disciplines, including Mechanical, Electrical, Industrial, Software, and other engineering disciplines. Students in Systems Engineering and Mechanical Engineering majors, however, formed the highest concentration of majors (n=26).

	Number	**Percent**
Mechanical Engineering	26	27.9
Systems Engineering	26	27.9
Electrical Engineering	16	17.2
Engineering Management	6	6.5
Software Engineering	4	4.3
Aeronautical Engineering	3	3.2
Computer Science	3	3.2
Industrial Engineering	3	3.2
Biomedical Engineering	1	1.1
Chemical Engineering	1	1.1

[1] All pre-survey responses were analyzed in the Interim Report.

Civil Engineering	1	1.1
Computer Engineering	1	1.1
Operations Research	1	1.1
Product Architecture	1	1.1
Total	93	100.0

Table 7: Breakdown of Student Majors in Matched Population

The breakdown by institution is as follows:

	Undergraduate SE majors	Undergraduates SE major + another major	Undergraduate majors/ Other	Graduate SE majors	Graduate majors:/Other
AFA	1	1 *[double major in Computer Engineering]*	4 *[2 Mechanical Engineering 2 Electrical Engineering]*	0	0
AFIT	0	0	0	2	1 *[Aeronautical Engineering]*
Auburn	0	0	2 *[1 Computer Science 1 Software Engineering]*	0	5 *[2 Computer Science 3 Software Engineering]*
CGA	0	0	11 *[Mechanical Engineering]*	0	0
Military Academy	1	1 *[double major in Engineering Management]*	2 *[1 Engineering Management 1 Operations Research]*	0	0
MUST	0	0	3 *[Mechanical Engineering]*	10	0
PSU	0	0	13 *[1 Engineering*	0	0

			Management 1 Chemical Engineering 3 Industrial Engineering 4 Mechanical Engineering 4 Electrical Engineering]		
SMU	0	0	2 *[2 Electrical Engineering (1 a double major in Marketing & Math)]*	0	0
Stevens	0	2 *[1 undergrad receiving SE certificate while majoring in Electrical Engineering; 1 undergraduate receiving SE graduate certificate while majoring in Mechanical Engineering]*	6 *[1 Mechanical Engineering 1 Civil Engineering 4 Engineering Management]*	0	1 *[Product Architecture]*
UMD	0	0	12 *[2 Mechanical Engineering 8 Electrical Engineering 2 Aeronautical Engineering]*	0	0
UVA	8	0	5 *[1 Biomedical Engineering 1 Computer Engineering 3 Mechanical Engineering]*	0	0

Table 8: Graduate and Undergraduate Systems Engineering and Other Engineering Majors by Institution

The 26 systems engineering majors (including double majors) were nearly evenly split between graduate students and undergraduates, but almost all of the non-systems engineering majors were undergraduates, as were almost all of those without systems engineering experience (either through courses, internships, or work):

	Graduates (n=14)	Undergraduates (n=49)
Systems engineering majors	12	14
Other majors	7	60
With systems engineering experience	11	23
Without systems engineering experience	3	26

Table 9: Graduate Vs Undergraduate-SE and Non SE Majors

Finally, it should be noted that the n's for each question analyzed may vary even within the matched set if a student did not answer a question or answered a question on the pre-survey but not on the post, and vice versa.

2.3 UNDERSTANDING OF SYSTEMS ENGINEERING

Systems engineering is a complex field that includes interdisciplinary approaches to design and problem solving; a corpus of diverse theoretical and practical models, and their pedagogical applications; and program offerings that vary institutionally at the undergraduate and graduate levels in curriculum design, course requirements and overall educational objectives (Brown & Scherer, 2000).

On both the pre- and post-surveys, students were asked to respond to the open-ended question, "What is systems engineering? Define it as best you can." Concise professional, technical, and academic definitions that summarized the field in terms of methodology, process, and discipline were found in documents created by military, aerospace, technical and professional organizations, including the Defense Acquisition University (DAU), the National Aeronautics and Space Administration (NASA NPR 7123.1A; NASA Systems Engineering Processes and Requirements), the International Council on Systems Engineering (INCOSE), the Institute of Electrical and Electronics Engineers (IEEE), and the Engineering Industries Association (EIA), and also in textbooks on systems engineering. Below are two examples, one from the DAU and one from NASA NPR:

> "For DoD, systems engineering is the set of overarching processes that a program team applies to develop an operationally effective and suitable system from a stated capability need. Systems engineering processes apply across the acquisition life cycle (adapted to each phase)

and serve as a mechanism for integrating capability needs, design considerations, design constraints, and risk, as well as limitations imposed by technology, budget, and schedule. The systems engineering processes should be applied during concept definition and then continuously throughout the life cycle….

Systems engineering is a broad topic that includes hardware, software, and human systems. It is an interdisciplinary approach for a structured, disciplined, and documented technical effort to simultaneously design and develop systems products and processes for creating and integrating systems (hardware, software, and human) to satisfy the operational needs of the customer. It transforms needed operational capabilities into an integrated system design through concurrent consideration of all life cycle needs. As systems become larger and more complex, the design, development, and production of such systems or system of systems (SoS) require the integration of numerous activities and processes. Systems engineering is the approach to coordinating and integrating all these acquisition life cycle activities. It integrates diverse technical management processes to achieve an integrated systems design" (Defense Acquisition University, 2011, p. 167).

"Systems engineering at NASA requires the application of a systematic, disciplined engineering approach that is quantifiable, recursive, iterative, and repeatable for the development, operation, maintenance, and disposal of systems integrated into a whole throughout the life cycle of a project or program. The emphasis of systems engineering is on safely achieving stakeholder functional, physical, and operational performance requirements in the intended use environments over the system's planned life within cost and schedule constraints" (National Aeronautical Space Administration, 2007).

Two sets of frequently occurring keywords were extracted from the definitions in these documents. The first set included eighteen non-technical words (including compound words) that relate to systems engineering; the second included 20 technical words that were more specific to systems engineering (List 1: generic systems engineering base words[2])

APPROACH	CUSTOMER	CROSS-DISCIPLINARY	DESIGN	DEVELOPMENT	DISCIPLINE
EFFICIENT	INTERDISCIPLINARY	MANAGE	MULTI-DISCIPLINARY	PROBLEM SOLVING	PROJECT
PRODUCT	PROCESS	REQUIREMENTS	SYSTEM	TEAM	TEAMWORK

Table 10: List 1 - Generic Systems Engineering Base Words

BALANCE	COLLABORATE	COMPLEX	COMPONENT	COMMUNICATION
CONCEPT OF OPERATIONS[3]	CYCLE	DEFINITION	DOCUMENTATION	INTEGRATE
LIFE CYCLE	NEEDS	RISK	SOLUTION	STAKEHOLDER
SUBSYSTEM	TECHNICAL	TECHNOLOGY	VALIDATION	VERIFICATION

Table 11: List 2 - Systems Engineering-Specific Terms

[2] Cognate and plural forms, not included in these lists, were included in the lists used in the analysis.
[3] AntWordProfiler, the concordance and text comparison tool that the assessment team used, did not allow for compound words to be examined. As a result, terms such as "concept [of] operations" or "life cycle" had to be split and analyzed as separate words.

Using a free, open-source application called AntWordProfiler,[4] lists of keywords were compared, first using the expert definitions and then student responses. A score of 100 percent for both lists would have included every single keyword but would not have been a readable or concise definition. One disadvantage to using AntWordProfiler was that it scored responses higher when keywords were repeated. To lessen this effect, we transformed the original data and definitions by removing duplicate terms and replacing them with non-keyword placeholders in order to avoid higher scores based on redundancy.

None of the expert definitions scored over 32 percent on either list. Thus when the expert definitions were entered into AntWordProfiler, the average score for List 1 was 15.8 percent, while the average score for List 2 was 19.96 percent. With one exception (INCOSE), the experts had almost twice as many words from List 2 compared to List 1. In other words, the experts used a higher percentage of the technical words than the generic ones. This confirmed that the two lists were distinct enough to make their use worthwhile.

Definition Source	List 1	List 2
Air Force Academy website	16.0%	32.0%
Institute of Electrical and Electronics Engineers (IEEE)	15.4%	23.1%
Engineering Industries Association (EIA)	17.1%	22.9%
International Council on Systems Engineering (INCOSE) 1	14.3%	10.2%
International Council on Systems Engineering (INCOSE) 2	18.6%	11.6%

Table 12: Percent of Words Used in Expert Definitions

In order to understand how such seemingly low percentages can apply to expert definitions, we need to remember that many of the words on the two lists are likely to be used only occasionally. The full definitions that were used are below, with List 1 words highlighted in red and List 2 words in highlighted in green:

AFA definition:

Systems engineering is an interdisciplinary engineering process that evolves, verifies, and documents an integrated, life-cycle-balanced set of systems solutions that satisfy customer needs.

[4] AntWordProfiler 1.200m was developed by Dr. Laurence Anthony, an English language professor at the Center for English Language Education in Science and Engineering (CELESE), School of Science and Engineering, Waseda University (Japan). According to Anthony's website, AntWord Profiler is "[a] freeware word-profiling program for Windows and Macintosh OS X, similar to Paul Nation's RANGE program." The RANGE program was originally developed by Nation to examine lists of common words and perform a concordance between various lists and journalistic and more literary texts in order to examine the number and types of words needed for reading and writing certain vernaculars (Nation I.S.P., 2004) (Nation, I.S.P., 2006). It was modified and re-envisioned by Anthony to meet his own research interests in corpus linguistics, genre analysis, and natural language processing.

IEEE definition:
Systems engineering is an interdisciplinary, collaborative approach that derives, evolves and verifies a life-cycle balanced system solution which satisfies customer expectations and meets public acceptability.

EIA definition:
Systems engineering is an interdisciplinary approach that encompasses the entire technical effort, and evolves into and verifies an integrated and life cycle balanced set of system people, products and process solutions that satisfy customer needs.

INCOSE definition 1:
Systems engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to operation. Systems engineering considers both the business and technical needs of all customers with the goal of providing a quality product that meets the user needs.

INCOSE definition 2:
Systems engineering is an interdisciplinary approach and means to enable realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem.

We expected that students entering Capstone courses without prior knowledge of systems engineering would initially produce responses using a lower percentage of both sets of listed words than the experts and that, as they increased in their systems engineering content knowledge and practical experience during the course of the year, they would continue to use the generic terms but add more of the technical terms. We also predicted that they would shift away from an understanding of systems engineering as a form of project management toward a more holistic understanding of systems engineering that included knowledge of systems, subsystems, life cycle models, etc.

Results

For List 1, the student percentage was only a few percentages points below the expert percentage in both the pre- and post-survey. For List 2, in contrast, it was substantially below even the INCOSE definition (11.6%). For both lists, the student averages increased from pre- to post-survey for the 84 matched students—those who responded to the question on both the pre- and post-surveys—although the changes were not statistically significant for either list:

List 1 Pre-Survey	12.35%	List 2 Pre-Survey	4.09%
List 1 Post-Survey	13.80%	List 2 Post-Survey	5.65%

Table 13: List 1 and List 2 Averages in Percent: All Students (n=84)

When we look at the subgroup with the least to learn—those who reported that they had prior systems engineering experience (including coursework)—we see that they began with slightly higher scores on List 1 and considerably higher scores on List 2. As might be expected, they did not improve very much:

List 1 Pre-Survey	12.83%	List 2 Pre-Survey	5.16%
List 1 Post-Survey	13.72%	List 2 Post-Survey	5.43%

Table 14: List 1 and List 2 Averages in Percent: Prior SE Experience (n=41)

However, when we look at the two subgroups with the most to learn—those who reported that they had no prior systems engineering experience (including coursework) and undergraduates—we see lower percentages at start and larger changes for both groups. We also see that those with no prior systems engineering experience not only gained more, but also ended with a slightly higher percentage gains than the entire group, indicating that SE Capstone courses had a positive impact on student learning of the terminology related to SE methodology, process, and discipline:

List 1 Pre-Survey	11.50%	List 2 Pre-Survey	2.96%
List 1 Post-Survey	14.33%	List 2 Post-Survey	5.93%

Table 15: List 1 and List 2 Averages in Percent: No Prior SE Experience (n=41)

List 1 Pre-Survey	11.88%	List 2 Pre-Survey	3.40%
List 1 Post-Survey	13.23%	List 2 Post-Survey	5.50%

Table 16: List 1 and List 2 Averages in Percent: Undergraduates (n=67)

Although the change was not statistically significant for either subgroup for List 1, it was significant for both subgroups for List 2. For students who did not have prior systems engineering experience, the List 2 post-survey scores increased significantly at the p =.00 level , $t(40) = 2.82$, $p \leq .01$, p = .007, d = 0.89. The strength of the relationship was ≥.5, a high categorization of strength (Cohen, 1988).

For undergraduates, List 2 scores also increased significantly at the $p \leq .01$ level, $t(66) = 2.64$, $p \leq .01$, d = 0.65. The strength of the relationship was ≥ .5, above medium categorization of strength (Cohen, 1988).

In other words, the greatest change was in the number of specifically systems engineering words (List 2) used by those with the least prior knowledge of systems engineering.

Case Study Analysis: The Bradley Fighting Vehicle

As a second, more holistic, way of assessing student understanding of systems engineering, students were asked to read and respond to a case study based on the well-known history of the U.S. Army's

development of the Bradley Fighting Vehicle (BFV). In many disciplines, case studies are used to generate classroom discussion, to help students develop their problem-solving skills and to force them to articulate the criteria they use when analyzing problem scenarios (Heywood, 2005). The case study was thus another way to evaluate the RT-19 students across universities, one that went beyond multiple choice questions or self-assessments.

The brief case study that was developed was based on research into the history and development of the Bradley Fighting Vehicle; a brief case study of the Vasa, another complex defense system in its time; and consultation with systems engineering professors at Stevens Institute of Technology. It included historical background information that described the vehicle's changing requirements; conflicts over safety and live fire testing; concerns such as documentation, time, and budget constraints; and professional ethics and communication. Film clips from *The Pentagon Wars,* a satirical portrait of the BFV's prolonged and embattled development process, were interspersed throughout the text as instructional anchors to make the assessment more engaging to students.

After reading the scenario and watching the clips, students were asked to respond to the following prompt:

> "Could the problems encountered in developing the Bradley Fighting Vehicle have been avoided? Explain your answer."

A slightly different prompt was used for the post-course case study analysis:

> "Now that you have completed a systems engineering project, do you think that the problems encountered in developing the Bradley Fighting Vehicle project could have been avoided? Explain your answer."

It was expected that prior to the course, the students would use mostly imprecise or generic terms to describe the problems encountered by the BFV developers and would have only vague ideas as to how to address them. After the course, in contrast, it was anticipated that they would incorporate more technical terminology and use more specific systems engineering concepts. For instance, if at first the students used general terms like "time," "money," or "politics," they could be expected to use more technical terms, such as "competing requirements," "stakeholder interests," "life-cycle models," etc., in their post-analysis.

Results

Given the open-ended nature of the prompt, the students' varied experience with systems engineering, and the diversity of their educational and disciplinary backgrounds, it is not surprising that there was a wide range of understanding exhibited in the first set of responses to the case study. For example, there were many responses that included only very vague descriptions of the BFV and inconclusive recommendations for the future, such as this:

"Problems could have been avoided if requirements were carefully followed and did not change so frequently. By keeping in mind what [the] vehicle was originally meant to do, the addition of extraneous features could have been avoided."

On the other hand, very few students had sophisticated analyses of the problems and recommendations for the future, using systems engineering terminology and concepts such as "product life cycle," "needs statement," "spiral development approach," etc. Here is one example of a more sophisticated response from the pre-case study analysis:

"Most of the issues addressed in the scenario could have been avoided with inclusion of some now common systems engineering practices and just a general focus on requirements validation. Requirements creep was the primary reason for most of the problems observed in the Bradley program. A PEO capable of maintaining a design baseline would have made a dramatic impact. As the program dragged on, new requirements were levied on the contractor and the design kept diverging from the original requirements. Although this is common, a spiral development approach could have accelerated the program and got a baseline configuration to the users. This would have resulted in a more focused test program because incremental testing would have identified problems earlier and it would have forced design and testing personnel to work towards a solution."

An analytic rubric was developed from the first set of student responses, with the goal of measuring increasing complexity of systems engineering knowledge.[5] A life cycle model provided a guide (Sage, 2000). Simpler responses were classified as addressing primarily the "Definition" phases, while more complex responses extended to the "Development" and "Deployment" phases:

[5] While rubrics are often developed before any documents are received—for example, to guide students in assignments--they can also be created a posteriori, after the data has been examined for patterns, as was the case here (Leydens, Moskval, & Pavelich, 2004).

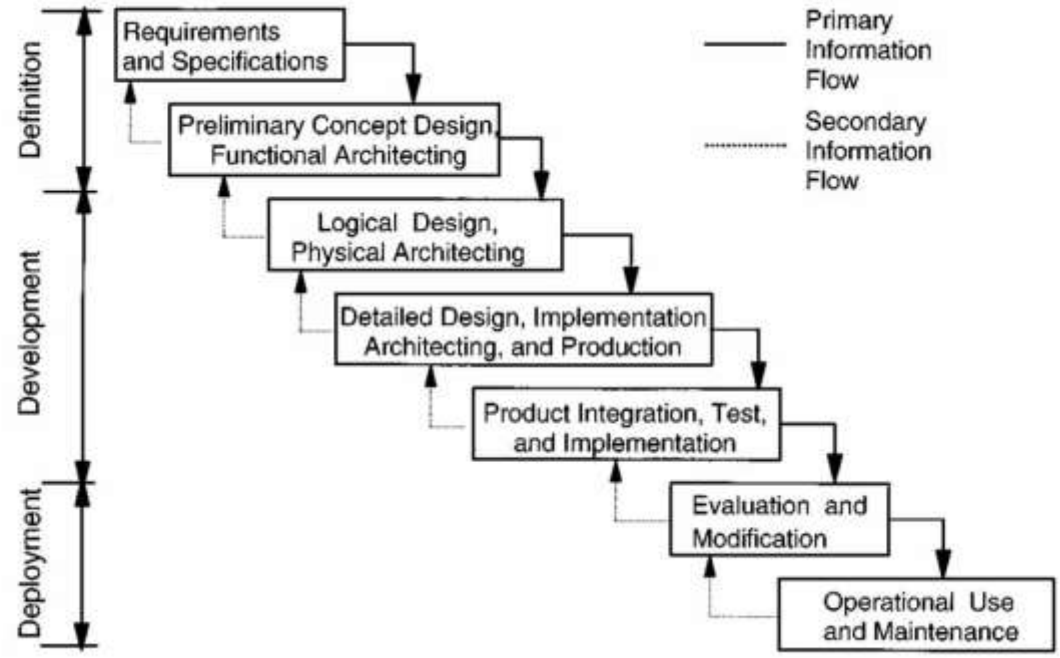

Figure 5: SE Life Cycle Model

The scoring rubric was divided in three categories:

A. **Demonstration of understanding of systems engineering as an approach to problem solving:** Identifies one or more central problems of the BFV using appropriate Systems Engineering vocabulary
B. **Demonstration of understanding of systems engineering as a process involving complex systems:** Provides recommendations and solutions to the problems mentioned in Category A, ideally moving beyond the requirements definition stage to later phases of development
C. **Demonstration of understanding of professional traits in the Systems Engineering discipline:** Any statement that implicitly or explicitly argues for the importance of communication, working in a team, and attending to ethical considerations when defining, designing, or developing a complex system.

Key competencies were selected from the SPRDE-SE/PSE Competency Model and mapped onto each category. The assumption was that when students identified some of the central problems of the BFV (e.g., requirements creep, failure to meet original product specifications, inattention to budget limits and safety issues, inattention to product life cycle, poor implementation of risk management plans, and miscommunication or lack of communication among different interests across various stages of the BFV's design), they also demonstrated understanding of select systems engineering competencies. These competencies also addressed potential solutions that could be provided to ameliorate or troubleshoot problems that ranged from the technical to the political.

The competencies chosen were the following:

Units of competency mapped to Category A:

#4 Stakeholder requirements definition – Element 4. Work with the user to establish and refine operational needs, attributes, performance parameters, and constraints that flow from the Joint Capability Integration and Development System described capabilities, and ensure all relevant requirements and design considerations are addressed.

#5 Requirements analysis – Element 5. Ensure the requirements derived from the customer-designated capabilities are analyzed, decomposed, functionally detailed across the entire system, feasible and effective.

#18 Requirements management – Element 23. Use Requirements Management to trace back to user-defined capabilities and other sources of requirements, and to document all changes and the rationale for those changes.

#27 Problem solving – Element 43. Make recommendations using technical knowledge and experience, developing a clear understanding of the system, identifying and analyzing problems using a Total Systems approach, weighing the relevance and accuracy of information, accounting for interdependencies, and evaluating alternative solutions.

Units of competency mapped to Category B:

#8 Integration – Element 11. Manage the technical issues that arise as a result of the integration processes that feed back into the design solution process for the refinement of the design.

#9 Verification – Element 13. Verify the system elements against their defined requirements (build-to specifications).

#10 Validation – Element 14. Evaluate the requirements, functional and physical architectures, and the implementation to determine the right solution for the problem

#19 Risk management – Element 24. Create and implement a Risk Management Plan encompassing risk identification, analysis, mitigation planning, mitigation plan implementation, and tracking throughout the total life-cycle of the program. Element 25. Apply risk management at the earliest stages of program planning and continue throughout the total life cycle of the program through the identification of risk drivers, dependencies, root causes, and consequence management.

#25 – System of systems – Element 41. Oversee the planning, analyzing, organizing, and integrating the capabilities of a mix of existing and new systems into a SoS capability greater than the sum of the capabilities of the constituent parts.

Units of competency mapped to Category C:

#26 Communication – Element 42. Communicate technical and complex concepts in a clear and organized manner, both verbally and in writing, to inform and persuade others to adopt and act on specific ideas.

#28 Strategic thinking – Element 43. Formulate and ensure the fulfillment of objectives, priorities, and plans consistent with the long-term business and competitive interests of the organization in a global environment

#29 Professional ethics – Element 56. Maintain strict compliance to governing ethics and standards of conduct in engineering and business practices to ensure integrity across the acquisition life-cycle

#24 Leadership – Element 40. Lead teams by providing proactive and technical direction and motivation to ensure the proper application of systems engineering processes and the overall success of the technical management process.

Two separate raters used a grading rubric comprised of the three categories described above (A, B, C), with each of the categories graded on a scale of 1 to 5 points. The lowest possible score was therefore three points (1 in each category) and the highest was 15.

Low answers (3-4), as demonstrated in the student example below, did not identify problems or make recommendations using appropriate systems engineering concepts and terminology. The response below scored a 4 on the rubric because it used vague language to identify problems with the vehicle's design (Category A, 2 points); it provided no concrete recommendations to solving some of the problems encountered (Category B, 1 point); and it also failed to mention any professional traits in the systems engineering discipline (Category C, 1 point):

> "The issue was a lack of aim for the vehicle. The goal of the project was changed so many times over, that by the end of the project, it did not even meet its original goals. If there had been a clear aim from the beginning, one that was not subject to so much change, the Bradley Fighting Vehicle may have just been a troop transport as intended."

Medium Low responses (5-7) satisfactorily used systems engineering language and concepts to identify problems and make recommendations related to the BFV's design and development process. In the student example below, the response was given a score of 7 because it identified the main problem as competing requirements (Category A, 3 points) and provided some recommendations to solving a cited problem (Category B, 3 points). However, no professional traits of systems engineering (Category C, 1 point) were discussed:

> "Yes, problems in the Bradley vehicle definitely could have been avoided. After going through the systems engineering course, I have learned that a large majority of your costs are committed once you begin designing your system. I learned that you actually commit to costs much ahead of actually spending the money. That's why it is important to make sure your original design meets all of the necessary requirements. With the Bradley, many of the requirements kept changing. This led to changes in the design and causing the cost of the project to reach astonishing levels. The Bradley could have been designed more effectively and much cheaper if the design requirements were constant."

Medium High responses (8-11) often provided a more holistic perspective of various problems experienced throughout the vehicle's life cycle, from the initial requirements phase to later verification and validation phases. The response below was given a score of 11 (Categories A and B, 5 points each,

Category C, 1 point) for citing complex systems engineering concepts such as iterative testing, systems integration, and trade-off analysis as important factors in improving the design process. However, this student did not discuss professional traits of systems engineering, such as improving communication with the design team or with stakeholders:

> "I think if they approached the Bradley project with a better iterative approach many of the problems could have been avoided. Each time a new design was developed, there was no design or cost trade-off analysis which would have helped evaluate what is important in the design. Per usual in systems design problems, the client did not know what they wanted and this led to multiple models being redesigned. If the Army had used smaller iterations in their designs, they could have expressed these changes to the client without getting so in depth with each model. There was also a lot of trouble resulting from poor systems testing. They chose to only test individual components and furthermore, to only do computer model simulation. This is a bad decision. If they had done real, fully integrated systems testing, they could have ensured the system will work in real life situations to maintain the safety of the troops using them. They also should have done user testing to get people who are unfamiliar with the exact design to test human factors. These testing techniques would have prevented conflicts among officers and the trials could have been avoided, saving both time and money.

Finally, <u>high responses (12-15),</u> although infrequent, diagnosed design problems and provided high-level recommendations using appropriate systems engineering terminology. Most important, unlike the lower responses, they were much more likely to reference the importance of communication, leadership, and aspects of the stakeholder and team relationship as integral to effective delivery and product function. The student response below received a high score of 13, with 4 points in Category A, 4 points in Category B, and 5 points in Category C. While the "Medium High" response above did better in Categories A and B by referencing multiple systems engineering concepts and phases of development, the response below performed better in Category C, and received 5 points because the student addressed issues of communication:

> "I think now after having completed a Systems Engineering project, it is easy to recognize the importance of several competencies that we used over the span of the project. Probably the most relevant competency to our project, and the Bradley Fighting Vehicle project is the concept of risk management. If the team in the BFV project would have had the foresight to use risk management, and alter the design when the risks became too high, a lot of time and money could have been saved. We had a similar experience during our semester, when one of the components in our project wasn't as useful as we had originally intended. To mitigate the risk, we drastically changed our design, which in turn saved us a lot of time continuing down a difficult path. The design change ended up saving our project and allowing us to complete our goals within the given time constraints. The next competency that was the most useful during the semester is the notion of communication. This competency also applies to the BFV project, because if strong communication was used between the team, and the customers that were funding the project, then different results could have been achieved. The most important task during communication is the requirements gathering process. It is necessary that both the team working on the project, and the customers funding the project are on the same page, and that the requirements are feasible given other constraints of the project. The bottom line is that not

> everything can be accounted for when performing any Systems Engineering project. However, if the team is adequately trained in the various competencies, the team will be able to quickly adapt and mitigate the risks that arise during the process and produce a product that still meets the requirements."

Each of the two raters first scored a set of 10 student responses for both the pre-and-post assessments. Inter-rater reliability was checked using Cohen's kappa. For Categories A and B, the Kappa statistics of .43 and .33 indicated moderate and fair inter-rater reliability, with the difference the result of one rater consistently scoring higher than the other.[6] In addition, the intraclass coefficient, another test of consistency using a one-way repeated measures ANOVA where raters (assumed to be randomly selected) were examined against their responses, gave significant results for categories A, B, and C: .71, $p>.001$.

Results

The PIs at seven schools (Auburn, UMD, Naval Academy, SMU, Stevens, UVA, Wayne State) assigned the scenario to their students at the beginning and end of the course, asking them to complete it individually outside of class. There were a total of 55 matched responses.

Student responses changed, although not dramatically, from pre- to post-course. Below is one example of a student who improved from an initial score of 4—the minimum was 3—to a post-response score of 8, or from "Low" to "Medium High":

Pre-course response:

> Yes. The issue was a lack of aim for the vehicle. The goal of the project was changed so many times over, that by the end of the project, it did not even meet its original goals. If there had been a clear aim from the beginning, one that was not subject to so much change, the Bradley Fighting Vehicle may have just been a troop transport as intended.

The student received a score of 4 because problems were identified in a vague manner (Category A, 2 points; Category B, 1 point), and because there was no mention of any systems engineering professional traits, such as improved communication between stakeholders and engineers (Category 3, 1 point).

Here is the same student's post-course response:

> Responding to this prompt at the end of the year, I think I am much better qualified to answer this from a systems engineering standpoint. Initially, it seemed like they had a clear purpose for the vehicle, to transport troops on the battle field. Still, it did not seem like they really designed this vehicle in a systematic way. The first step would have been to identify the problem, perhaps that the army did not have an agile troop transport for the battlefield. The next step would have been to come up with use cases for such a transport and from there to get a list of requirements. In the actual situation, there were constant changes that altered the design, that were not part of the initial requirements and that changed the vehicle entirely. Perhaps, some

[6] While the guidelines for Kappa agreement beyond chance have been debated, .43 is acceptable for most purposes (Banerji, Capozzoli, McSweeney, & Sinha, 1999, p. 6).

> of these features were needed, but the project would have benefitted greatly from trade off analysis, something that was never performed. If initially the vehicle was to have no weapons or armor, and carry 7 troops, it may be acceptable that certain features are added that reduce the capacity to carry personnel, but that is a decision that should be made in a controlled way, not on a whim. Overall, the vehicle design and project as a whole was a failure from a systems stand point and it is clear why systems engineering is a growing and much needed field.

This response demonstrated an ability to identify problems with Bradley Fighting Vehicle's design and development by describing the impact of competing requirements (A, 3 points). In addition, the student provided recommendations from a systems standpoint using systems engineering language, as evidenced by the references to tradeoff analysis and problem definition that moved beyond the requirements phase of development (B, 4 points). While there was no explicit reference to any professional traits of systems engineers, such as communication or leadership (C, 1 point), overall the student demonstrated improved knowledge of systems engineering processes, terminology, and understanding of problem areas and received a final total score of 8, compared to the initial score of 4.While a total score of 8 is only on the midpoint of the scoring scale, this improvement is reasonable given that the student reported on the pre-survey that he had no prior experience in systems engineering.

The scores for the entire matched set of students increased from pre- to post-, particularly for the more technical Categories B and C:

	Pre	Post
Category A	2.76 (1.04)	3.09 (1.05)
Category B	2.69 (1.08)	3.43 (0.88)
Category C	1.59 (1.00)	2.19 (1.27)
All categories	7.04 (2.60)	8.70 (2.26)

Figure 6: BFV Rubric Means and Standard Deviations-All Students (n=54)

The increases were statistically significant at $p < .01$ for all categories combined, as well as for Category B and Category C, but not for Category A:

For combined scores, $t(53) = 4.39$, $p<.01$, $p=.000$.

For Category A, the category related to understanding systems engineering as a problem solving approach, $t(53) = 1.72$, $p>.05$, $p=.092$.

For Category B, the category relating to systems engineering as a process involving complex systems, $t(53) = 4.22$, $p<.01$, $p=.000$.

For Category C, the category related to their understanding of systems engineering as a discipline requiring specific professional traits, $t(53) = 3.25$, $p<.01$, $p = .002$.

As the means below show, students with systems engineering experience were initially 1.32 points above students without this experience but by the end the difference was only .36 between the two groups.

Pre- Course Case Study	7.32 (2.47)
Post-Course Case Study	8.86 (2.27)

Table 17: BFV Means and Standard Deviations - Students with SE Experience (n=28)

Pre- Course Case Study	6.00 (2.28)
Post-Course Case Study	8.50 (2.28)

Table 18: BFV Means and Standard Deviations - Students without SE Experience (n=16)

The increases were statistically significant at the p > .01 level for students both groups:[7] students without prior SE experience, t(15) = 5.37, p<.01, p=.000; students with prior SE experience, t(27)=2.61, p<.01, p=.007.

Use of the Bradley Fighting Vehicle Case Study Analysis in the Course
Faculty used the BFV scenario in different ways. Several used it as an instructional activity—for instance, for initiating discussion on systems engineering and ethics. At the Air Force Academy, for example, the PI reported that the scenario provided a useful framework to introduce students to their semester projects and to the ethical questions that might arise. In his report, he noted that the instructor had had the students watch the entire film of *The Pentagon Wars* (not just the clips), leading to a "discussion [that] was by far the best SE related discussion the team had all year. All members were involved, even the non-SE ones. We will very likely repeat the movie day in the coming year. It was good for engineering ethics…"

At Auburn, the PI also used the scenario to generate class discussion and found that "it provided a good means of motivating a systems outlook." On the other hand, the assessment team at Penn State felt that the prompt did not give enough guidance as to the depth of the expected response.

2.4 STUDENT USE OF BLOGS

One of the assessments was a weekly weblog ("blog") post. Blogs are defined as "dated [online] entries made of text containing news, commentary or reflections, with links to other artifacts such as websites, photos or other media…[and] functionality for outside commentary by peers, [teachers or others] at a distance" (Chen et al., 2005). Blogs have been used in higher education contexts as knowledge logs to gather information about specific ideas or topics, records of personal life, assessment tools, forums for interacting and communicating with others; and platforms for task management (Sim & Hew, 2010). In

[7] The n for this test was 41; 10 students from the post-scenario group (originally n=52) could not be matched with their original systems engineering surveys, which had asked for student status and systems engineering backgrounds.

this project, the weekly blogs were centralized in Sakai, the content management system provided by Stevens that has a built-in blogging module. Eight institutions used the blog to track project progress and describe the research, acquisitions, development, and testing phases of their designs.

The students were asked to answer several prompts in each of their posts:

- What did you and your group accomplish this week?
- Which SE competencies best align with what you did this week?
- What specifically did you do in terms of each of these competencies?

While each university originally proposed researching a specific DoD target area, there were often multiple team projects being developed at each university so that blog entries reflected the diversity of the projects. At UMD, for example, one group of students blogged about integrating two different types of software used to model micro fluidic particle steering while another group blogged about building an energy-efficient wireless sensor network to track intruders and monitor a secure area. At SMU, one team researched developing a facial capture application without facial markers while another team described the process of developing custom gesture software. Part of the class at the Coast Guard Academy worked on building a flare tube redesign while the other group engineered a hybrid vehicle (mail truck) with an electric motor capable of regenerative braking. At other institutions, student teams worked collaboratively on one project.

In their blogs, the students described the phases of the systems engineering design process, including researching initial product ideas and platforms; calculating and recalculating their original costs; purchasing materials; meeting with customers to discuss product specifications; visiting offsite locations to learn about fabrication techniques and systems integration; testing and modifying designs; and lastly, presenting before advisors and clients and evaluating the projects of their peers.

The types of problems that student teams described in their blogs included making design tradeoffs; providing adequate security for their (wireless) products; relying too much on knowledge or technical skills of one team member with a specific area of expertise; setting reasonable and achievable goals for product design within a school year; struggling to communicate between members of an interdisciplinary team with many different perspectives and varying levels of expertise; and managing time and design constraints.

However, the students took different approaches to the weekly online postings, and answered them with varied degrees of diligence, depending on the extent to which their instructions enforced the use of the prompts. At one end of the spectrum were students who wrote clear, highly technical narrative descriptions of their projects and tied these clearly to the systems engineering competencies. The following, from Auburn, is an example:

Group 3 - Week 11 (3/31/11 - 4/6/11) symonwi@auburn.edu (06-Apr-2011 12:47:27)

Group 3 Week 11 Update Blog

4/6/11
Group #3

This week we began the integration of our two main subsystem, the QARSP (iRobot) system and the mobile device. Up until this point no communication has actually occurred between the mobile device and the QARSP itself. In addition to these two main systems our server infrastructure was also utilized as the "middle man" in the overall system. Before integration we had previously sent dummy data from the mobile device to the server and from the server to the QARSP so we were fairly competent that integration would go smoothly. We began the integration process by defining for the final time exactly what data we need to transfer from one system to the other and how this data would be formatted. This allowed us to easily build interfaces into both the mobile device and the QARSP to receive and process this data accordingly. It was important to look at the needs of both systems when establishing the format for the data so that we could ensure that needs of both of the systems were meet with a minimal amount of post processing on either end.

Once a data format had been established the communication protocols were put into place. The main concern here was how often data would be sent to and polled from the server. We established a polling rate that was significantly higher than the sending rate to ensure that new data was received promptly. With our communication protocol established we then proceeded to send actual data between the systems. At this point, the data we sent was again dummy data to ensure that we knew what values should be received on the opposite end.

After a successful communication test, the final step of integration was to send actual request from the mobile device to the QARSP and ensure that the QARSP operated correctly. The initial tests we ran in this manner were successful. At this point we feel confident that the interface between our two systems is working the way we originally planned.

The goals for the final week of cycle three will be to perform a complete test of the entire system as well as adding in a few additional features. We have a final mobile device, of a different os, that we want to install the communication on as well as updating the hard drive on the QARSP system to a solid state drive to improve reliability. In addition our AR Drone system was returned late this cycle. Initial testing could not determine if all of the issues had been resolved with the AR Drone but we will continue looking into this during the final week.

SE Competencies Covered:
- Implementation - progress made on implementation of the overall system, at this point system is to a point where extensive testing can begin.
- Reliability, Availability, and Maintainability - Came into effect when deciding the final mobile device to implement the system on as well as deciding if it was worth it to update the hard drive in the system to a solid state drive.
- Requirements Analysis - We had to ensure that the test results we were collecting matched the original requirements we established at the beginning of the project.
- Integration - Integration was completed this week between the two main systems of our project.
- Interface management - an interface had to be established and documented for communication between the different components of the overall system.
- Software Engineering - good engineering practices had to be applied to the code we wrote to add functionality to the system as well as the "glue" code used to connect the different components of the system.
- Communication/Problem Solving/Strategic Thinking/Professional Ethics - As always these competences were important during the implementation and execution of our project.

Figure 7: Blog Example #1

Another example, while less detailed and not written in narrative form, provided information about the current phase of the project—building a hybrid vehicle—and also tied it to the competencies:

RT 19 ID	RT19015
Week	1
Question Number	Question
1	What did you and your group accomplish this week?
Answer	• Generated a Mission Statement for the product. o A mission statement may still be required to cover the project that will define the product. • Conceived a new hybrid system that allows a high efficiency ICE to provide improved urban and highway performance. (Schematic is attached) • Drafted an "Operational Modes" statement to explain the system function and why it is superior to any current Hybrid or plug-in system.
2	Which SE competencies best align with what you did this week?
Answer	Awareness of different generations of electric vehicle products and energy (Continued study of hybrid architectures) Develop competence with structured tools. (AHP homework.) Be aware of multiple functions in creating a new product (Homeworks have developed awareness of players)
3	What specifically did you do in terms of each of these competencies?
Answer	• Awareness of the efficiency and interactions of the components of a hybrid vehicle system. • Awareness of the inefficiencies of current hybrid vehicles and plug in vehicles. • Awareness of the impossibility of launching an entire new vehicle as a carrier for upgraded technology. • Awareness of the practicality of converting an existing OEM vehicle platform to include the new power train. • Generated a Mission Statement for the product. o A mission statement may still be required to cover the project that will define the product. • Conceived a new hybrid system that allows a high efficiency ICE to provide improved urban and highway performance. (Schematic is attached) • Drafted an "Operational Modes" statement to explain the system function and why it is superior to any current Hybrid or plug-in system.

Figure 8: Blog Example #2

On the other end of the spectrum, students provided details about their projects sparingly and answered the given prompts in a cursory fashion, either by listing numerical competencies or failing to include any competencies or narrative detail:

Facial Recognition Weeekly Report 04-4-11 kejones@mail.smu.edu (05-Apr-2011 14:31:34)

What did we accomplish this week?

We are able to place a box around the face and eyes on the depth map. We wrote and turned in a paper to an ieee conference.

SE competencies:
#7 Implementation and #26 Communication

What I did:

I oversaw the implementation of drawing the boxes on the depth map. For #26 I was part of the team that wrote the IEEE paper for the SEIDS '11 conference.

Figure 9: Blog Example #3

Other students did not answer the given assessment prompts and instead used the blog site as an online portal to store such digital media items as PowerPoint presentations, conference posters, links to project documentation in Google Docs, and photos and videos of their designs. In one case, students provided brief updates and artifacts of SE documentation, including a bill of materials, Gantt charts, QFD report, periodic design evaluations and types of analyses.

Here is an example of an entry with a link to a GoogleDoc report:

Microfluidic Particle Steering Device Update bnguyen3@mail.umd.edu (17-Nov-2010 20:39:43)

This week, my group has been working on defining use cases and scenarios for our microfluidic particle steering device. The use cases will be used to develop activity and structure diagrams in order to determine the requirements and parameters of the system.

Next week we hope to explore the possibilities of modeling the system in Modelica and interfacing it with MagicDraw software.

Below is a link to our GoogleDoc, in which we design and analyze our system.
http://bit.ly/arP39S

Figure 10: Blog Example #4

This is an example of an entry that included a photograph:

The Hybrid Vehicle team has completed fabrication of a polycarbonite safety guard. This guard will mitigate safety issues with the system, and help prevent both electical shock hazards and entanglement hazards while still allowing the team to keep an eye on the system.

Please note the guard still has a protective film on it which will be removed prior to testing.

Figure 11: Blog Example #5

Of all of the student blog posts, the final prompts at the end of the capstone experience generated the greatest opportunity for reflection. The prompts for the final post were:

- What were the most important system-level trade-offs that you had to consider during this project?
- If you were to start this project over again, what would you do differently?

Many students reported that if they could have changed anything about their projects, they would have set more realistic goals for themselves at the beginning of the year, or would have set “intermediate goals” on a week-to-week basis, rather than just “cycle goals.” Here is an example:

- “When coming up with your own project, never try to do more than you can accomplish. I remember at the very beginning that we wanted to do a lot with our system. As time [went] on, we realized we were trying to do too much.”

Students discussed having to make trade-offs throughout the development process, including having to purchase cheaper or substitute components; piling less requirements onto their original design; changing development platforms because of performance issues; and modifying their designs to meet DoD standards. Some students felt that rather than attempting to design a fully operable system or product, they should have designed a functional prototype. Others reported that they relied too much during the acquisitions process on the assumption that outside vendors would keep to an efficient shipping schedule, and discussed how they would plan more in the future to accommodate possible delays into product development. One student described wanting to begin the integration process sooner:

- "The lessons we learned from this were not to rely on the documentation of a product as proof that it will actually do what it says and to start the integration process as soon as possible, even if it is just in a limited testing mind set. If we were to begin again, we would start attempting the integration as soon as possible, even if it was just with dummy data, to ensure that our interface worked the way we intended."

Another student described how creating and managing documentation was an important aspect of systems engineering that had not been encountered before in other coursework:

- "I was not aware of the amount of types of documentation that a systems engineering project required. The different competencies like requirements management and verification and validation showed how important organizational aspects are to a successful project. I think they resulted in a higher quality project."

A theme in the final blogs was teamwork, with students discussing the advantages and disadvantages of working in multidisciplinary teams:

- "Because it was multidisciplinary, I feel it was more like a job in the real world than other projects. Sometimes projects can be self-contained, but a lot of times it requires a wealth of knowledge and because people come from different backgrounds, it is easy to play off of an individual's strengths. The only tasks that were difficult were the ones not covered by anyone in our team, i.e. software knowledge. None of us truly brought our specific disciplines into the project but because we were all trained to think differently and are different people, it ended up being a great dynamic."

Toward the end of the semester, as students worked on performing final tests on their prototypes and working with their teams to draft presentation documentation, many posts reflected this plateau in project trajectory – students at multiple institutions repeatedly cited "communication" as an important competency:

Week of 5/2 John Forrest (02-May-2011 10:33:59)

Following the dry run presentation we discovered there was a lot in our final report and presentation that the professors weren't looking for. A lot of effort was spent on re-writing the documentation to meet the criteria outlined by the professors during the dry run. The presentation itself was actually quite an awakening, the comments from the professors were blunt and to the point and definitely caught our group off guard.

While scrambling to prepare the documents, our team also managed to achieve 2 more gestures to present during our final. This week we presented our final to the professors and our customer, and they seemed pleased with the results. Charles flew out to Virgnia to present and the conference also went well.

The competencies we used in our final week: 26 communication (presenting, writing documentation), 7 implementation (the new gestures), 10 validation (validating the final system), and 22 software engineering.

Figure 12: Blog Example #6

Student teams posted weekly standalone entries, as they were assigned to do, but did not use the threaded discussion feature of the blog to respond to each other's post. Only two of the PIs and mentors used the blog for occasional updates on student progress, syllabus changes, and course assignments. However, one PI noted in his final report that "few if any students have been viewing the information" that he had posted. Only one mentor submitted a post, responding to a student question about how to define a needs statement.

2.5 BENEFITS AND CHALLENGES OF SYSTEMS ENGINEERING FROM THE STUDENTS' PERSPECTIVE

Although the students did not reach the level of experts in terms of their understanding of systems engineering terminology, they nevertheless greatly appreciated the contribution a systems engineering perspective had made to their projects. Thus in response to an open-ended question that asked if what they had learned about systems engineering had benefitted their capstone projects, all but a small percentage said that it had done so at least somewhat, and most said it had definitely done so.[8] This was more the case for those with prior systems engineering experience than for those without, but 79 percent of all groups had a positive response:

	All (n=55)	With SE experience (n=34)	With no SE experience (n=25)	Undergraduates (n=44)	Undergraduates with no SE experience (n=24)
Yes	82%	88%	76%	77%	71%
Somewhat	5%	6%	4%	9%	8%
No	13%	6%	20%	14%	21%

Table 19: Student Appreciation of SE Approach on Their Capstone Projects

Those who responded that systems engineering had benefitted their projects wrote about how it helped them systematically work through the entire design and creation cycle:

- "Yes, many of the concepts helped in the original planning of the project. It allowed us to systematically go about the design and implementation of our system. While I'm sure we would've worked everything out without it, systems engineering provided that general framework for designing our system."
- "Yes. I think our learning benefited us when we were defining our requirements, developing our conceptual design, and by giving us a procedural and logical way to make decisions."
- "Yes - the most intangible positive effect that I found was an almost continuous attention to the system-level view and the execution of the systems engineering process."
- "Absolutely, when we started we first had to define the problem through stakeholder analysis, we then created alternatives, came up with a scoring method, scored each system, compared them for tradeoffs, and gave a recommendation. We followed the Systems Decision Making Process in order to solve the problem."

Those who felt that it had not been helpful were generally those who worked only on narrow projects or small subsystems rather than as part of larger interdisciplinary teams. They came from different universities, so this was not an opinion held by others at the same school:

---

[8] This analysis uses the matched set for which we have both pre- and post-surveys in order to correlate with prior experience. Note again that students from Penn State and UMD did not have the opportunity to answer this question; Penn State because the full post-survey had not been designed by the end of the first semester, when Penn State students completed their course, and UMD because they used the pre-survey for the post-survey. In addition, not all students in the matched set answered this question.

- "Not really, the courses focused more on robotics."
- "Not for my project. There really was not much that went into it. My group did the flare tube modification where it was just a new mounting system and did not require any other areas of engineering."
- I do not think it benefited it. It was not really applied.

However, the introduction of systems engineering had added a level of complexity to their Capstone projects that had its own challenges. In response to an open-ended question that asked the students to describe the most challenging aspect of their project, the most common challenges overall were managing the dynamics of a multidisciplinary group and communication problems. Group organization and communication were the most commonly listed issues, with those with no prior systems engineering experience more likely than the other groups to list communication issues. In the table below, the highest percentage for each issue is highlighted in gray:

	All (n=62)	With SE experience (n=34)	Without SE experience (n=29)	Undergraduates (n=48)	Undergraduates without SE experience (n=25)
Group organization and work	23%	21%	24%	25%	24%
Communication issues	23%	18%	28%	21%	28%
Defining the requirements	16%	18%	14%	10%	12%
Constraints of time and/or budget	15%	18%	10%	15%	12%
Technical problems	13%	18%	7%	15%	8%
Defining the problem	11%	9%	14%	15%	16%

Table 20: Most Challenging Aspects of SE Capstones from Students' Perspective

Some of those whose greatest challenges were classified as issues of group organization wrote about the difficulties of managing large interdisciplinary groups:

- "Organization in such a large team. 9 people may not sound like a lot, but 9 people with up to 6 simultaneous jobs and conflicting schedules was a substantial task."
- "The most challenging aspect was working with a lot of people from different majors around campus. It was difficult to work together and figure out the best solutions."
- "The most challenging aspect of the project was working with so many different engineering disciplines. A recurring problem was that some of the disciplines were too focused on their

particular system and didn't look at the project as a whole and see the effects their design would have on the whole base."

- "Communication between different majors and finding time to meet at the same time."
- "Getting people from different academic backgrounds to work together towards the same goal."
- "Being able to successfully coordinate across disciplinary boundary. Work efficiently in such a big team."
- "Collaboration between several different engineering disciplines."

Others wrote about how their groups struggled because they lacked members from other disciplines:

- "When trying to design an electronic system, without members who are familiar in electronics design, made the project much more difficult."
- "Not knowing anything about electrical or network components and we didn't have anyone in the group who was knowledgeable about this which would have helped."
- "As a team of mostly systems engineers with one mechanical engineer and one computer scientist, this project was an extreme challenge. We would have liked an electrical engineer and more mechanical engineers as we knew very little about the mechanics of the system and how we could physically transmit data in a water source. However, this allowed us to learn about each of the elements we would not have otherwise."

These issues came up across universities and seem to have been specific to the group the student was assigned to.

Closely related were difficulties with communication, in part because some were at a distance:

- "Having an outreach student. While our outreach student contributed greatly to the overall success of our system, it was sometimes difficult to explain the software aspects of the system without a hands-on approach."
- "Communication between local and distance members due to communication channels."
- I am a distance student and it was not being able to get hands on lab time with actual system components.
- "My travel, which placed me in several different time zones a week. This caused me problems in figuring out at what time I needed to dial into class or team functions."

Others wrote about the difficulty they had defining the problem:

- "The initial problem statement was the most challenging because we did not have a defined problem to begin with that did not already have a solution."
- "The most challenging aspect was determining what the actual problem was that we needed to solve, and then developing a scoring process that accounted for everything that was important for training."

- “The initial problem definition was the most challenging. You have to be solving the correct problem in order for your work to have any meaning. Defining the correct problem will save you a lot of heartache later.”

Closely related were issues with defining and meeting the requirements:

- “Fitting the project to the requirements, i.e. making it “cool” while still making it meet the expectations presented to us at the beginning of the semester.”
- “Meeting the goals of the pilots, aircrews, and the Coast Guard all in one. In addition, producing something that could meet all of those criteria.”
- “Most challenging was trying to determine what the DoD would want from us. Even with a set of requirements that are sliding at times we are trying to determine what decisions are in the best interest of the DoD for the particular need for which we were hired. We had to remember not to offer things that were not requested.”
- “The most challenging part of our project was validating that our project met our derived requirements.”

In addition, the time frame and budget created constraints that were difficult for some to overcome:

- “Time management, we selected too many features making our project a bit too ambitious, and therefore we struggled to make ends meet for deliverables, causing delays and lower results than expectations.”
- “The most challenging aspect of our project was meeting the deadlines we set for ourselves. We got all of our requirements done (except one) but we were just barely behind for most of the project.
- “TIME. We were crunched to produce an artifact on time that would meet requirements.”
- “The most challenging aspect of the project was the acquisition of materials. Our team was instructed to try to obtain materials by soliciting donations from manufacturers. Our attempts to do so, however, were overwhelmingly unsuccessful, leading to a large delay in the project. We were forced to order materials ourselves and are awaiting reimbursement.”

2.6 STUDENT PERCEPTION OF PRODUCT SUCCESS

Despite the challenges, 82 percent of the students from 11 institutions who responded to the post-survey question, “Did your group produce a product that you would consider a success?” felt that it was:

	Frequency	Percent
Yes	83	82.2%
No	18	17.8%

Total	101	100%

Table 21: Percent of Students Who Considered Their Projects a Success - Global Data

Although there was a range among universities, at no university did less than two-thirds of the students feel that their projects were a success. At two universities, Stevens and the Coast Guard Academy, 100 percent felt that this was the case, followed by Auburn (93 percent), UVA (92 percent), and SMU (83 percent):

		Frequency	Percent
AFA	No	1	25.0%
	Y	3	75.0%
	Total	4	100.0%
AFIT	N	2	66.7%
	Y	1	33.3%
	Total	3	100.0%
Auburn	N	1	7.1%
	Y	13	92.9%
	Total	14	100.0%
CGA	Y	17	100.0%
MA	N	1	25.0%
	Y	3	75.0%
	Total	4	100.0%
MUST	N	4	26.7%
	Y	11	73.3%
	Total	15	100.0%
NA	N	1	33.3%
	Y	2	66.6%

	Total	3	100%
PSU	N	5	33.3%
	Y	10	66.7%
	Total	15	100.0%
SMU	N	1	16.7%
	Y	5	83.3%
	Total	6	100.0%
Stevens	Y	7	100.0%
UVA	N	1	7.7%
	Y	12	92.3%
	Total	13	100.0%

Table 22: Percent of Students Who Considered Their Projects a Success - By Institution

Completing the project seemed to be a likely but not necessary correlate of success, and it therefore seemed possible that students could consider their projects successful even if they were not completed. An open-ended section of this question allowed students to explain their answers; all but one did so.

There were four main reasons students considered their projects a success, with some students listing more than one reason. The fact that the project fulfilled customer and system requirements was the most frequently cited reason, closely followed by the fact that they had produced a functional prototype. As expected, there was variation among institutions depending on the project, problem area and design of the course. For example, students at Penn State, who spent a one-semester capstone course working through systems engineering modules and experienced systems engineering instruction delivered via lectures and guest speakers, overwhelmingly cited exposure to SE concepts and processes as their reason for considering their product a success, while students at Stevens reported finding solutions to a real-life problem as their top reason. Most of the students at UVA who created a haptic

glove cited having a functional prototype as the reason for success, followed by discovering solutions to real-life problems. At the Coast Guard Academy, students most frequently cited fulfilled requirements as a measure of product success, followed by providing solutions to real-life problems: Why Students Felt their Projects Were a Success[9]

	Produced a functional prototype	Used SE concepts/processes	Fulfilled requirements	Solved real-life problems
AFA			4	
Auburn	2	2	5	1
CGA	1		8	5
MUST	4	2	5	
PSU	2	8	2	1
SMU		1		
Stevens	4	2	1	5
UVA	10	3	2	5
USMA	1		1	2
USNA		2		
Total	24	20	28	19

Table 23: Why Students Felt their Projects Were a Success

Here are some sample responses:

- “The most successful part of the project was the learning experience. In every other engineering class I have taken, we have explicitly focused on the development of a single component or small system.” (Used SE concepts/processes)
- “Our ultimate objective was to lower the amount of fuel and water used within the bases. We achieved that goal by designing various systems which work together to lower those numbers significantly.” (Solved real life problems; fulfilled requirements)
- “While the product is only a proof of concept, we were able to show that the basic design elements of the product would indeed work in the field. Many of the design elements were results of the client's feedback and with consideration of the Soldier in mind.” (Fulfilled requirements)
- “[Our product] was manufactured by a Coast Guard Unit and was received very positively with

[9] Student responses to this question were not mutually exclusive; several students cited one or more reason for achieving product success, including those who also noted that their product had flaws or was only a proof of concept.

our interaction with many different Coast Guard assets." (Fulfilled customer requirements; solved real life problems)

- "Our group offers a design that will decrease convoys to Forward Operating Bases by 50%." (Solved real life problems)
- "We came together and made sure that our sub-systems worked cohesively. We didn't just make separate sub-systems in the hopes that they would sync up and work together. We created an entire functioning systems engineering solution that is a huge success." (Used SE concepts/processes)
- "We all worked together and designed a product that we were able to test, demonstrate, and present to many different companies and symposiums effectively." (Produced a functional prototype)
- "The most successful aspect of the project was the excellent group dynamic and time management of the team." (Used SE concepts/processes)

The eight students who felt that their projects were not a success were spread across seven institutions. Their responses included the same four main reasons. Not producing a prototype was <u>not</u> the most common reason cited, which was lack of resources:

	No physical prototype produced	Technical problems with prototype	Did not fulfill requirements	Lack of resources, budgetary & time constraints
AFA	1			
Auburn		1		
MUST			1	4
SMU			1	
UVA		1		2
USMA				1
USNA			1	1
Totals	1	2	3	8

Table 24: Why Students Did Not Feel Their Projects Were a Success

Here are some sample comments:

- "[The project] scope was changed. I think more time and the right resources were needed in order for the product to have been successful." (Lack of resources, budgetary and time constraints)
- "Our schedule is off from the typical schedule and we got a late start. We are still working on our product." (Time constraints)

- "We completed all of our objectives, but one component of our project, the mobile surveillance platforms, had two parts in which one was completed successfully and where the other was not due to a manufacturing defect in the system." (Technical problems with prototype)
- "We did not develop the product that we had in mind. This was due primarily from difficulty in ordering of parts and a team member not doing his part." (Did not fulfill requirements; Lack of resources, budgetary and time constraints)

In addition, some of the students who did consider their projects a success nevertheless noted that there was still work to do. They stated that the prototypes were only proof of concept and therefore not fully operational, needing further testing and refinement:

- "I believe that we produced a successful prototype. It meets the requirements that we set out to meet, however the overall quality of the system was lower than we would have liked due to the short development time and the limitations of the baseline software. However we know enough to design and implement a production quality system." (Time and technical constraints)
- "With more time we would have completed a great amount of verification and validation leading us to a result in which we can place far more confidence." (Time constraints)
- "At this point [the haptic glove] just needs more gestures implemented" (Time and technical constraints)

Ranking of Items

The students were asked to rank seven items in terms of their perceived usefulness in learning about and applying systems engineering. The items were:

- Faculty course lectures
- Reading material provided by faculty
- Faculty advisors
- Department of Defense mentor(s)
- Industry mentor(s)
- Members of my team in my own engineering area
- Members of my team from other engineering areas

The table below has the mean scores by institution. Since the highest ranking was 1 and the lowest was 7 (with a N/A choice included), lower mean scores indicate higher approval ratings. Where the means are very low (as with USMA's rating of faculty advisors) or very high (as with SMU's rating of team members from other engineering areas), there was a high level of consistency—in the case of USMA, for example, every student had faculty advisor as the first choice. In addition, for some students an item could be Not Applicable (N/A), which was not counted in the means, while other students at the same school could rank that same item a 1 or 2, presumably because some items were applicable to some of the participants but not others. In addition, there was often very little consistency within a school. For example, at one school "team members from other areas" was ranked first by two students, second by

two students, fourth by two students, fifth by two students, and seventh by one student. In this table, the lowest and highest scores for each institution are highlighted in green (lowest) and green (highest):[10]

	AirForce (n=6)	Auburn (n=14)	CGA (n=17)	MUST (n=16)	SMU (n=6)	Stevens (n=7)	UVA (n=13)	USMA (n=4)	AFIT (n=3)
Course lectures	5.40	3.46	4.59	3.31	3.33	3.33	3.89	4.67	4.33
Course reading material	5.50	4.17	3.64	4.57	3.67	3.00	4.82	3.50	4.67
Faculty advisors	4.20	3.29	3.42	3.71	3.83	4.00	3.09	1.00	1.67
DoD mentor(s)	3.00	4.27	4.82	4.58	3.00	3.50	4.83	5.75	4.50
Industry mentor(s)	3.00	4.91	3.50	4.77	3.50	5.40	5.09	4.00	4.50
Team members own area	2.60	3.08	2.94	2.85	4.00	4.43	3.25	3.75	3.00
Team members other areas	4.50	3.33	3.78	3.73	6.00	4.00	3.23	4.75	4.00

Table 25: Ranking of Items From Students Perspective

There are a few patterns across the entire set of schools. Team members from the students' own engineering areas were rated most valuable for four of the seven institutions and were consistently rated as more useful than team members from other engineering areas. In addition, industry mentors were rated as the least valuable in four of the seven schools.

2.7 PERCEPTIONS OF CHALLENGES: PRINCIPAL INVESTIGATORS VS. STUDENTS

Student Perceptions of Challenges

Students across institutions shared many of the same challenges, regardless of their course status, engineering background, or whether or not they came from military or civilian schools. They reported challenges in defining a problem, organizing and communicating in an interdisciplinary team, and having to limit project scope because of time and budgetary constraints, or because of unrealistic expectations or inability to meet customer or system requirements. Students also described part acquisition, lack of technical expertise, systems integration, and fulfilling changing requirements as other factors that they negotiated in their attempts to design systems.

AFA- parts acquisition; defining customer needs & requirements

AFIT- systems integration; delegating tasks & time management

Auburn- parts acquisition; systems integration; fulfilling requirements; time constraints; limiting project scope; organizing a large interdisciplinary team

CGA- lack of technical expertise in certain areas; problem definition; organizing and communicating with a large interdisciplinary team; testing the final prototype

[10] This is an analysis of all responses, not the matched set. There were no responses from Penn State because this question was not added until the final survey in May and none from UMD because they responded to the baseline survey both pre- and post-implementation.

MUST - limiting project scope; constantly changing requirements; time constraints; lack of technical expertise in certain areas

"Most challenging was trying to determine what the DoD would want from us. Even with a set of requirements that are sliding at times we are trying to determine what decisions are in the best interest of the DoD for the particular need for which we were hired. We had to remember not to offer things that were not requested."

"It was very heavy in electrical and communication engineering. I am a mechanical engineer so I had to immerse myself into several aspects of electrical operation and wireless communications in order to design my parts of the project correctly."

Penn - limiting project scope; parts acquisition; fulfilling requirements; lack of technical expertise; organizing and communicating with a large interdisciplinary team; problem definition; time & budgetary constraints; systems integration:

"Although our project is not quite finished, I would consider it a success because of how much we accomplished in such a short period of time. Yes, one way to define success might be accomplishing what you set out to do. But to me, success is also how much you've accomplished and how close you come to reaching something desired. The most challenging thing was probably narrowing this large project into something much smaller that would be achievable in a limited amount of time with limited funds."

"We have designed a system that does accomplish the main requirements that we were given. Most of the team members are not familiar with programming and electronics. We had to learn a lot on the fly and most of the design work was done by very few individuals."

SMU *- lack of technical expertise in certain areas; limiting project scope; organizing a large interdisciplinary team; problem definition*

Stevens *- organizing and communicating with a large interdisciplinary team; allocating resources & delegating tasks; parts acquisition*

UVA - *organizing a large interdisciplinary team; allocating resources & delegating tasks; limiting project scope; fulfilling requirements; lack of technical expertise in certain areas; systems integration*

"As a team of mostly systems engineers with one mechanical engineer and one computer scientist, this project was an extreme challenge. We would have liked an electrical engineer and more mechanical engineers as we knew very little about the mechanics of the system and how we could physically transmit data in a water source. However, this allowed us to learn about each of the elements we would not have otherwise."

UMD - students did not answer this question

Wayne - students did not answer this question

USNA - parts acquisition; organizing a large team; allocating resources & delegating tasks

USMA - problem definition; time constraints

Principal Investigator Perceptions of Challenges

PIs reported challenges related to course scheduling and grading. There was little preparation time for PIs to recruit many students for the fall semester. PIs reported improved spring semester recruitment. At institutions such as CGA, Stevens, and SMU, PIs reported that there were advising/grading discrepancies between students' disciplinary advisors and their Capstone course instructors and that future RT-19 efforts should streamline course requirements and grading.

PIs at AFA, Auburn, Penn, SMU, and USNA all discussed how Systems Engineering was a complicated topic with content that was difficult to teach. PIs were challenged by having to balance overseeing students' capstone designs in addition to instructing them in systems engineering concepts. At Penn, for instance, the PI reported that students were able to grasp certain SE competencies, such as requirements definition and communication, but were less able to understand modeling, verification, and validation because of lack of time and the complexity and newness of the material. PIs also cited communication between mentors as another challenge; this ranged from no communication (if students did not have mentors) to infrequent communication. One PI reported that students misinterpreted mentor feedback due to lags in communication. However, when mentors were in regular contact with students or had the opportunity to visit them for design reviews, the impact was reported as beneficial.

Other challenges included team formation and communication between on-campus and remote students; time and workload management; and DoD problem areas that required complex technical knowledge.

PIs from each participating RT-19 school reported the following challenges

AFA- teams spent considerable time grasping the scope of the project; too many systems engineering managers on one team; and students were not good at scheduling. Students had initial problems understanding what the requirements were and how the Requirement Traceability Matrix connected to their projects/designs; students also had to learn how to work on an interdisciplinary team with roles as Systems Engineers, Systems Engineering Managers, and disciplinary engineers

AFIT- short time frame to recruit students; course scheduling issues - students were committed to their schedules in the first semester. "With all students carrying four courses during the fall quarter, we were not able to do much on the design & integration for this project. We were able to put purchase orders and contract tasks in place to support the effort, to include the technician support for hardware integration & flight testing."

Auburn - recruiting was a challenge since students already registered; the case study included programming language that was more complex than students were prepared for; students did not experience DIACAP (security standards) until late in the semester. They could have benefited from earlier introduction and identification of security vulnerabilities in their systems. Content was difficult

for students to grasp and they came away with basic concepts in SE

CGA - would like more consistency between grading of capstone majors; "we are removing some of the layers of advisors from projects"

MUST - "student recruitment was a challenge because of short time frame;" students did not know about systems engineering and were therefore disinterested; forming teams was a challenge, as was communication between on-campus and distance students; students did not have interdisciplinary experience but the issues were lessened by external SMEs so they could focus on SE approach and less on technical, discipline-specific issues. The problem area was difficult for students to grasp; professor will try to map lectures more closely to students' systems

Penn - students had more deliverables than capstone course; students demonstrated lack of understanding in their presentation of verification & validation, but otherwise grasped many SE concepts, delivered a prototype on time, worked capably in teams and proved that they had achieved valuable skills & knowledge

SMU - students had to drop a requirement due to lack of access promised by client; had issues with remote communication between clients & students; communication between industrial mentors, faculty & students was not smooth and may have been because of mentors' obligations; grading criteria for students from different departments should be more uniform next year. Also students experienced changing requirements from clients and sometimes misinterpreted the feedback. Similar to Penn: students grasped some competencies very quickly, but more complicated ones like Verification, Validation; Availability & Maintainability; Modeling & Simulation were less well-practiced because of schedule constraints.

Stevens - professors from different engineering departments experienced conflict in grading and course expectations vis-a-vis the SE project, since multiple disciplines were involved. Students did not always know whom to respond to or whose advice to follow (their SE professor or individual disciplinary advisor)

UMD- undergraduate students had difficulty using simulation/modeling software tools; PIs had trouble recruiting students in fall & experienced short preparation time

Wayne- students were too busy to blog and felt like course expectations and workload were at times "overwhelming;" PIs had trouble with limitations imposed by school IRB protocol on administering assessments

USNA - Mentors came in too late to help students; students had trouble grasping SE content; PI delivered SE content to students through DAU material, but it was not applicable to their learning. They had difficulty grasping the difference between requirements and specifications. Students had trouble working across disciplines in addition to learning SE content

USMA - Students spent too much time on stakeholder analysis & requirements development; did not

have as much time to work on testing physical prototype; students did not work with industry mentors until 2nd semester

3.0 ANALYSIS OF INTEREST IN DOD PROBLEM AREAS AND SYSTEMS ENGINEERING CAREERS

3.1 STUDENT UNDERSTANDING OF DOD PROBLEM AREAS

One goal of RT-19 was to expand students' awareness of the number and variety of Department of Defense problem areas that require systems engineering expertise. To assess change, a question on both the pre- and post-surveys asked the students to list three engineering problems that they believed were currently being addressed by the Department of Defense. There were 93 matched pre- and post-survey responses to this question.

There were three major changes from pre- to post-survey. First, on the pre-survey, 14 percent of the responses were blank, compared to only 6 percent on the post-survey. Second, on the pre-survey, 25 percent of the responses were too vague to be considered responsive to the question—for example, problem areas described as “training soldiers,” “electrical,” “new platform development,” or “awareness.” The percentage of vague responses was reduced to 16 percent on the post-survey. Third, there was a large increase from pre- to post-survey in the percentage of students who did not list a DoD problem area as such but listed systems engineering issues (“requirements management,” “requirements creep,” “not meeting deadlines”). Only 7 percent of the responses could be categorized this way on the pre-survey compared to 20 percent on the post-survey—in fact, this was the most common response by that time.

The specific areas chosen by the students were coded as follows:

Problem area	Including…
Energy-related	Energy efficiency, green energy, renewable energy, alternative energy, fuel economy
Weapons/weapons systems	Weapons acquisition, missile systems, fighter planes, better guns
Field needs	IED detection, troop protection, expeditionary housing, water filtration, lightweight armor
Systems engineering	Requirements management, requirements creep, system integration, not meeting deadlines
Cyber security/Internet security	Cyber security, secure communication, cyber defense
Communication/communications systems	Communication, communication networks, real-time information, inter-systems communication
Autonomous vehicles	AUVs, remote aerial vehicles, military robotics, unmanned systems
Humanitarian assistance	Humanitarian assistance, disaster relief
Border security	Border security, border defense, border surveillance
Training needs	Troop training, virtual simulations, immersive training
Other	RFID, materials science, situational awareness, nanotechnology, sensors, etc.

Table 26: Student Perception of DoD Problem Areas

The area that increased the most was the energy-related problem area, particularly energy efficiency and green energy. The area that decreased the most was weapons and weapons systems, which were in any case mostly listed by the military academies and decreased somewhat as these students shifted to other problem areas, some more related to their projects. Other areas only shifted slightly in one direction or the other. The following tables list problem areas from highest to lowest percent:

Table 27: Pre/Post survey responses - Problem Areas from Student Perspective

	Pre-survey responses by problem area		Post-survey responses by problem area		
	Number of responses	Percent of all responses	Number of responses	Percent of all responses	% CHANGE
Energy related	29	13%	40	17%	4%
Weapons/weapons systems	28	12%	21	9%	-3%
Field needs	19	8%	7	3%	-5%
Systems engineering	15	7%	46	20%	13%
Cyber security/Internet security	15	7%	21	9%	2%
Communication systems	12	5%	9	4%	-1%
Autonomous vehicles	10	4%	9	4%	0%
Humanitarian assistance	9	4%	3	1%	-3%
Border security	4	2%	4	2%	0%
Training needs	4	2%	3	1%	-1%
Other	23	10%	32	14%	4%
Vague	57	25%	36	16%	-9%
TOTAL	225	100%	231	100%	

Although it might have been expected that on the post-survey, at least one of the three items would relate to the problem area the student's institution had chosen to work on, in fact the students seem to have interpreted the question to mean "other" DoD problem areas. For example, the Air Force Academy's chosen problem areas were solar energy and low-power computing, yet only one student

mentioned solar power as a DoD problem area and none mentioned low-power computing. Similarly, MUST focused on immersive training technologies, yet not one student mentioned this as a DoD problem area. Instead, the students tended to focus on areas that are in the news (cyber security, green and/or renewable energy, energy efficiency, border security, humanitarian assistance, etc.) or, for those in the military academies, part of their daily lives (autonomous vehicles, field safety, systems for servicing troops in remote areas, etc.). The one exception was the Coast Guard Academy, whose problem area was green power generation and whose students listed fewer weapons systems and more energy-related responses on the post-survey.

3.2 INTEREST IN SYSTEMS ENGINEERING CAREERS

A major goal of the RT-19 project was to increase student interest in systems engineering. The pre- and post-course surveys therefore included a question designed to see if there was a change in this area. The question was as follows:

On a scale of 1 to 5, with 5 being the highest, how interested are you in the following?

Q1: Becoming a systems engineer
Q2: Becoming a systems engineer for the government
Q3: Becoming a systems engineer for private industry

The 5-point scale ranged from “Not at all” (1) to “Very much” (5).

Since it was possible that the matched set of responses was biased in one direction or the other, we compared the baseline (pre-course survey) responses for the matched set with the baseline responses for the entire set. The table below shows the difference in terms of numbers of students. It is important to note that 26 percent of the respondents in the matched set were from military academies and 74 percent were from civilian institutions, close to the 29 percent and 71 percent in the total pre-survey population:

Pre-Course Survey Responses on SE Career Interest: All Students and Matched Set of Responses

	All students		Matched set	
School	Number	Percent	Number	Percent
AFA	8	2.8%	6	6.7%
AFIT	3	1.0%	3	3.4%
Auburn	38	13.2%	5	5.6%
CGA	13	4.5%	10	11.2%
MA	4	1.4%	4	4.5%

MUST	18	6.3%	12	13.5%
PSU	56	19.4%	13	14.6%
SMU	17	5.9%	2	2.2%
Stevens	42	14.6%	9	10.1%
UMD	23	8.0%	12	13.5%
UVA	33	11.5%	13	14.6%
Total	288	100%	89	100%

Table 28: Pre-Course Survey Responses on SE Career Interest - All Students and Matched Set of Responses

The pre-survey means on the career choice question for the matched population were higher for all three questions compared to the pre-survey means for the total population, suggesting that the matched population was somewhat biased toward systems engineering in general:

	Q1 General	Q2 Government	Q3 Industry
All respondents (n=288)	3.42 (SD: 1.44)	3.03 (SD: 1.45)	3.11 (SD: 1.44)
Matched set (n=89) [11]	3.71 (SD: 1.34)	3.22 (SD: 1.36)	3.45 (SD: 1.31)

Table 29: Means and Standard Deviations for Systems Engineering Career Choices by Careers

When split into student groups by status (undergraduate and graduate), the means in the matched population were again higher than the means for the total group. In all cases, the means for graduate students were higher than the means for undergraduates. As might be expected, undergraduates were more interested in systems engineering careers in a general way than in becoming a systems engineer for a specific employer group. Graduate students and post-graduates presumably already knew their career paths:

	Q1 General	Q2 Government	Q3 Industry
All undergraduates (n=156)	3.12 (SD: 1.46)	2.77 (SD: 1.44)	2.95 (SD: 1.39)
Matched set undergraduate (n=73)	3.66 (SD: 1.38)	3.18 (SD: 1.37)	3.36 (SD: 1.34)

[11] Although there was a total matched population of 93, cited elsewhere, three students did not answer this particular question on the baseline survey, leaving a population of 89 for this question only.

All graduate students (n=118)	3.75 (SD: 1.32)	3.31 (SD: 1.41)	3.25 (SD: 1.47)
Matched set graduate students (n=16)	3.94 (SD: 1.18)	3.44 (SD: 1.32)	3.88 (SD: 1.01)
Postgraduates (n=10)	4.00 (SD: 1.41)	3.50 (SD: 1.58)	3.50 (SD: 1.58)

Table 30: Means and Standard Deviations for Systems Engineering Career Choices by Class Status

Finally, the means for students with prior systems engineering experience were again higher for the matched group. But whether for the unmatched or matched group, these means were even higher than the means for graduate students or postgraduates, suggesting that these students in particular already knew their career paths. Further evidence is provided by the low standard deviations, which show there was little range within the group:

	Q1 General	Q2 Government	Q3 Industry
All students: No prior SE experience (n=172)	3.02 (1.46)	2.74 (1.47)	2.77 (1.43)
Matched set: No prior SE experience (n=43)	3.05 (1.38)	2.81 (1.37)	2.91 (1.34)
All students: Prior SE experience (n=116)	4.01 (1.19)	3.46 (1.33)	3.62 (1.33)
All students: Prior SE experience (n=40)	4.45 (0.82)	3.73 (1.24)	4.08 (0.97)

Table 31: Means and Standard Deviations for Systems Engineering Career Choices by SE experience

The fact that the matched population was somewhat more predisposed to systems engineering careers than the total population raises the possibility that there would be less change in this smaller population than there might be in the population as a whole. In addition, student interest was already relatively high (at the mid-point or higher in the Likert scale), which leaves less room for improvement than if interest had been low at the start. It therefore seemed likely that the greatest improvement would come within the group with no background in systems engineering.

3.3 POST-SURVEY RESULTS

Post-survey means for the matched population as a whole increased for Q1 (general) and Q3 (industry) but remained essentially the same for Q2 (government):

	Q1 General	Q2 Government	Q3 Industry
Baseline	3.71 (SD: 1.34)	3.22 (SD: 1.36)	3.45 (SD: 1.31)
Post-survey	3.84 (SD: 1.34)	3.20 (SD: 1.33)	3.69 (SD: 1.27)

Table 32: Post Survey Results-Q1, Q2, and Q3 Means and Standard Deviations. All respondents (n=89)

For those with prior systems engineering experience, the means for Q1 (general) and Q3 (industry) increased, while the mean for Q2 (government) decreased:

Q1 Pre-Survey	4.45 (0.82)	Q2 Pre-Survey	3.73 (1.24)	Q3 Pre-Survey	4.08 (0.97)
Q1 Post-Survey	4.50 (0.78)	Q2 Post-Survey	3.55 (1.32)	Q3 Post-Survey	4.22 (0.83)

Table 33: Post Survey Results-Q1, Q2, and Q3 Means and Standard Deviations-SE Experience (n=40)

For those without prior systems engineering experience, however, the means for Q1, Q2, and Q3 increased with the mean for Q3 (industry) increasing the most:

Q1 Pre-Survey	3.05 (1.38)	Q2 Pre-Survey	2.81 (1.37)	Q3 Pre-Survey	2.91 (1.34)
Q1 Post-Survey	3.26 (1.43)	Q2 Post-Survey	2.95 (1.23)	Q3 Post-Survey	3.28 (1.33)

Table 34: Post Survey Results-Q1, Q2, and Q3 Means and Standard Deviations-No SE Experience (n=43)

Despite the increases, a paired-samples t-test showed no significant differences between baseline and post-survey means for either group in all three questions. For students with SE experience, the results were as follows: t(39) = 0.31, *p*>.05, *p* = 0.76; for interest in systems engineering careers in government t(39) = -0.88, *p*>.05, *p* = 0.39; or for interest in systems engineering in industry: *t*(39) = 0.80, *p*>.05, *p* = 0.43. For students without SE experience, the results were as follows: for general systems engineering career interest, t(42) = 0.98, *p*>.05, *p* = 0.34; for interest in systems engineering careers in government, t(42) = 0.57, *p*>.05, *p* = 0.57; and for interest in systems engineering in private industry, *t*(42) = 0.98, *p*>.05, *p* = 0.34.

However, means can obscure subtle changes. Another way to look at the change from pre- to post-survey is to look at the change in the percentage of students at each point in the Likert scale. For example, for Q1 (general systems engineering career interest), about 65 percent of students on the pre-survey chose 4 or 5, indicating high interest. This percentage increased to about 70 percent on the post-survey, with a distinct shift from 4 to 5. The same was the case, although to a lesser extent, for Q3 (working in industry). In the tables below, the choice with the greatest change is highlighted in gray:

	Baseline %	Post-survey %
1	12.4	11.6
2	6.7	4.7
3	13.5	14.0
4	32.6	27.9
5	34.8	41.9
	100.0	100.0

Table 35: Post Survey Results-Q1 General

	Baseline %	Post-survey %
1	16.9	15.1
2	11.2	15.1
3	24.7	23.3
4	27.0	27.9
5	20.2	18.6
	100.0	100.0

Table 36: Post Survey Results-Q2 Government

Q3 (Industry)

	Baseline %	Post-survey %
1	15.7	11.6
2	4.5	4.7
3	19.1	16.3
4	40.4	38.4
5	20.2	29.1
	100.0	100.0

Table 37: Post Survey Results- Q3 Industry

If we break the matched population of students into three subgroups—low (scoring 1-2), medium scoring (3), and high (scoring 4-5)—we see that there was no consistent pattern or concentration of students from one institution in the low-, medium-, or high-scoring categories. For example, for the post-survey scores for Question 1 (general systems engineering interest), the Coast Guard Academy had the greatest percentage in the low-scoring category, UMD had the greatest percentage in the medium-scoring category, and PSU/UVA had the greatest percentage in the high-scoring category. In fact, PSU, UVA, and MUST had the highest percentage in the high category for all three questions. It is notable that the schools whose students expressed the highest interest in systems engineering careers in government were not the military academies.

The tables below look at the percent that each institution contributes to each category (low, medium, high). The largest percentage in each column is highlighted in gray.

	% low	% medium	% high
AFA (n=6)	15.8	0	4.9
AFIT (n=3)	0	8.3	3.3
Auburn (n= 6)	10.5	0	6.6
CGA (n=11)	21.1	25.0	6.6
MA (n=4)	0	0	6.6
MUST (n=13)	10.5	16.7	14.8
PSU (n=13)	10.5	8.3	16.4
SMU (n=2)	5.3	8.3	0
Stevens (n=9)	10.5	0	11.5
UMD (n=12)	0	33.3	13.1
UVA (n=13)	15.8	0	16.4
Total	100.0	100.0	100.0

Table 38: Post Survey Results- Q1 General. Breakdown by Partner Institution

	% low	% medium	% high
AFA (n=6)	10.7	0	7.1
AFIT (n=3)	0	4.5	4.8
Auburn (n= 6)	10.7	4.5	4.8
CGA (n=11)	21.4	9.1	7.1
MA (n=4)	0	0	9.5
MUST (n=13)	10.7	13.6	16.7
PSU (n=13)	17.9	4.5	16.7
SMU (n=2)	3.6	4.5	0
Stevens (n=9)	3.6	27.3	4.8
UMD (n=12)	7.1	22.7	11.9
UVA (n=13)	14.3	9.1	16.7
Total	100.0	100.0	100.0

Table 39: Post Survey Results- Q2 Government. Breakdown by Partner Institution

	% low	% medium	% high
AFA (n=6)	14.3	0	5.6
AFIT (n=3)	0	5.9	3.7
Auburn (n= 6)	14.3	0	5.6
CGA (n=11)	19.0	23.5	5.6
MA (n=4)	0	0	7.4
MUST (n=13)	4.8	17.6	16.7
PSU (n=13)	14.3	5.9	16.7
SMU (n=2)	4.8	5.9	0
Stevens (n=9)	9.5	11.8	9.3
UMD (n=12)	4.8	23.5	13.0
UVA (n=13)	14.3	5.9	16.7
Total	100.0	100.0	100.0

Table 40: Post Survey Results- Q3 Industry. Breakdown by Partner Institution

If we run pair-samples t-tests, we find that the increase from low- up toward high-scoring is statistically significant for the low-scoring group for all three choices (Q1, Q2, Q3) and for the high-scoring group for two of the three choices (Q2, Q3) but not for any of the medium-scoring group:

Low scoring: In the low-scoring group, we found a statistically significant increase in the means from baseline to post-test in all three choices, with the significance for the last two choices at the more stringent .01 level. Thus student means increased significantly from baseline in general systems engineering interest $t(14) = 2.23$, $p<.05$, $p = 0.04$; for interest in becoming a systems engineer for government from baseline $p<.01$, $p = 0.001$; and for interest in becoming a systems engineer for industry, from baseline: $t(16) = 3.79$, $p<.01$, $p = 0.002$).

Medium scoring: For students who were categorized in the medium-scoring group, none of the changes were statistically significant. Thus responses for question 1 increased from their pre- to post-test means, but not significantly: $t(9) = 1.25$, $p = 0.244$). Student pre-test means for question 2 decreased slightly at post-test, but not significantly: $t(17) = -0.21$, $p = 0.834$. Finally, the group of students in the mid-range

group increased in their interest in becoming a systems engineer for private industry, but again at a level that was not statistically significant: $t(13) = 1.17$, $p = 0.26$.

High scoring: For students in the high-scoring group, there was a mixed picture, depending on the choice. Thus baseline means for general systems engineering interest decreased in the post-test, but not significantly $t(57) = -0.87$, $p>.05$, $p = 0.39$. For systems engineering careers in government, baseline means also decreased in the post-test, this time at a statistically significant level $t(40) = -4.39$, $p<0.01$, $p = 0.00$; as did baseline means compared to post-test means in terms of their interest in working for private industry, although this decrease was not significant $t(5) = -1.11$, $p>.05$, $p = 0.27$.

More research is needed to better understand these changes and the subtleties in movement in Likert scale responses.

3.4 STUDENTS' REASONS FOR ENTERING THE SE PROFESSION

The previous career question asked the students if they would choose a career in systems engineering, but did not say when. However, when the students were given an open-ended question that asked if they would choose a career in systems engineering and to say why, 55 (80 percent) of the 69 who answered the question said that they would, and many indicated that this would be sometime in the future, after they had spent time in their own engineering track. Only 14 students (20 percent) said they would not, generally because they already had plans for a career in a specific engineering discipline.

It was notable that money was almost never listed as a reason. The largest number was drawn to systems engineering because they liked being able to see the larger picture:

- "Yes, I would. I would love being a systems engineer working on complex projects especially in the DoD arena. As a SE I can see the whole picture of the project from the beginning to the end of its life cycle in addition to understanding the system's features inside out. Moreover, as a SE, I get to work in and with other disciplines and engineers that it really helps me to understand the project from different perspectives."
- "I would choose a career in system engineering because for every project that I am involved with, I like to have an overall understanding of the system. A career in engineering is not just finishing my assignments and making money for the family, it is about delivering a wonderful product that meets customer needs within budget and meets the schedule."
- "Yes, because I love working on huge projects and managing a whole lot of people. It's a pain sometimes, but it's so rewarding in the end to see the final huge project. I learned a lot and I really am considering a career in systems engineering because I had a blast working with all of the people in my group."

They also liked the variety of projects that face a systems engineer:

- "In the future I may decide to pursue a career in systems engineering because you're exposed to a wide variety of areas, not just one specific area. The projects in systems engineering vary much more than in individual engineering fields."

- "Yes. The projects are always varying, and it's a more philosophical approach to engineering. Maintaining the technical details will be important, but having the flexibility to think about alternative designs based on systems engineering principles is more enticing."

And finally, they liked the challenges posed by working on a large system, the ability to see the process through from beginning to end, and the interdisciplinary and problem-solving aspects of systems engineering:

- "Yes, systems engineering is a very diverse field with what seems like a fast pace and constant change. In addition, it seems like a job that would be challenging both on an intellectual level as well as a practical level. All of these reasons make systems engineering seem like a good career choice to me."
- "Yes, systems engineering allows an individual to be a part of many stages in a solutions process. This fact allows for a robust and challenging experience, which appeals to me."
- "Yes, as a systems engineer it's your job to make sure all of the pieces fit together in a project, which is a challenge in itself and one of the things that separates good products from bad product."
- "Yes, it is interesting to be able to break a project down and analyze it based on different factors in order to prove it is a viable and cost effective project."
- "Yes, I enjoy the detailed nature of the process as well as the satisfaction of a good complete design."
- "Due to the fact that systems engineering is an interdisciplinary field and requires a thorough understanding of a number of working principles, I would choose a career in it."
- "Yes. I feel like as an engineer I have struggled to find my niche as I like so many different facets of Mechanical Engineering and engineering in general. SE allows me to learn many different fields and develop a specialization as I develop as a systems engineer."

When the question was posed in an even broader fashion, the responses were even more positive. Thus in response to the question, "Do the approaches and models of systems engineering seem applicable or useful to your engineering studies and future plans," 67 students answered and 64 of them agreed.

While this might be assumed to be the case for graduate students, it was the case for undergraduates as well. Only three of the 49 undergraduate students who answered this particular question did not perceive systems engineering to apply to their future career or studies. One of the three wanted to work as a discipline-specific engineer, while two did not want to be engineers at all.

The other 46 undergraduates (94 percent of those who answered) cited one or more reasons why systems engineering would be applicable and useful to their future career plans and studies, including:

- Practically applying systems engineering concepts such as requirements analysis, lifecycle models, problem definition, and project/risk management to design.
- Working in interdisciplinary teams on complex, real-life problems with tangible customers and outcomes.

- Experiencing firsthand the communication needs and demands of their teams and clients.

The most commonly cited reason was that systems engineering concepts could facilitate the design, research and development process (they listed Requirements Analysis, Complex Systems, Subsystems, Integration, Life Cycles, and Project Management), followed by working on interdisciplinary teams: [12]

Use of systems engineering concepts	23
Working on interdisciplinary teams and problems	16
Gaining real life experience	14
Improving verbal communication/written documentation	5

Table 41: Why Systems Engineering Would Be Useful and Applicable to Future Career Plans and Studies

Sample responses include:

- "Yes, regardless what I do in the future, systems engineering has given me a broad perspective on the application of various fields. "“Yes because projects are becoming more and more complex and today's engineering feats combine so many different disciplines. Therefore it is so important to understand systems engineering and be able to operate with different disciplines to form one cohesive project.”
- “Yes, the methods of tracking requirements and specifications will be extremely applicable in the engineering world as design teams become more global. The need to share information and document clearly when and where a decision oriented and why is extremely important in a multinational design system.”
- “Yes, they teach very well how teams of people from different backgrounds should communicate and work together. In the real job world almost all teams consist of people from different academic backgrounds so it is very useful.”
- “Systems engineering will be applicable to my future plans. I will be joining the military and knowing how the various systems I come into contact with work together is important.”
- “Future work will require design and integration of new and legacy systems. In order to accomplish these efforts, an understanding of interfaces, project requirements, system functions, and their interdependencies will be needed to field a system given the anticipated constraints of budget and schedule. The SE approaches and models help focus these efforts.”
- “The approaches and models allow you to systematically outline requirements of the customer and then craft out steps to be followed to achieve these requirements. Where changes are made to any of the design requirement, the models would be modified accordingly to align with the customer. Everything about systems engineering is essentially about the customer.”
- “[Systems engineering approaches and models] help me to see the big picture of the projects that I am involved in. Proper management of the project saves time and money because it clearly defines the end result, the testing and verification process.”

[12] Student responses were not mutually exclusive; several students cited more than one reason for the relevance of systems engineering to their future career plans and studies.

- "I have found the greatest success when working with people with different backgrounds and using a systems engineering approach. This approach includes the management of the project throughout its entire life cycle."

4.0 RT-19 PRODUCTS: DISSEMINATION, COURSE MATERIALS, AND ONLINE REPOSITORY

Products of RT-19 can be classified into several categories:

- Student products, which include prototypes and posters
- Faculty and research team products, which include a variety of course materials, including assessments; publications and papers; and interim and final reports.
- The development of a learning community and online project repository

4.1 STUDENT PRODUCTS

One requirement of all SE Capstone projects was the development of an artifact or prototype. The production of physical prototypes (hardware and software) was a key deliverable designed to help a diverse population of students learn and apply systems engineering learning. Examples of student prototypes follow.

Figure 13: Stevens Institute-Expeditionary Housing

Figure 14: Penn State-Humanitarian Assistance/Disaster Relief Kit

Figure 15: Military Academy- Immersive Training

Figure 16: SMU - Immersive Training

Video examples include:

Auburn University

http://swemac.cse.eng.auburn.edu/~umphrda/sysEng/RT19/Team1Video.wmv

http://swemac.cse.eng.auburn.edu/~umphrda/sysEng/RT19/Team2Video.m4v

http://swemac.cse.eng.auburn.edu/~umphrda/sysEng/RT19/Team3Video.mp4

http://swemac.cse.eng.auburn.edu/~umphrda/sysEng/RT19/Team4Video.avi

Missouri S&T

http://msmovie.mst.edu/public/misc/immersion vest.wmv

Southern Methodist University

http://www.youtube.com/watch?v=xoE9y2hjMSA

Stevens Institute of Technology

http://www.youtube.com/watch?v=ThYZEw7YNbg

University of Virginia

http://www.youtube.com/watch?v=N6dw15marHo&feature=youtu.be

US Military Academy

http://vimeo.com/27850108

In addition to these products, 26 papers and posters were published and presented at engineering education and systems engineering conferences such as the American Society of Engineering Education, INCOSE, SIEDS and NDIA presenting the diverse approaches undertaken to SE Capstone courses, the learning gains, student projects, and other student outcomes recorded, and the challenges addressed within the particular types of universities in which the courses were implemented.

Dissemination of the RT19 pilot program was facilitated through different venues. Partners were encouraged to participate in conferences, symposiums, panels. The following list shows the participation of students and faculty members in such events

1. National Defense Industrial Association, 12th Annual Science & Engineering Technology Conference. Charleston, South Carolina. June 21-23, 2011

Student Poster Presentations:

- Missouri (5 posters)
- Wayne State (3 posters)

- Penn State (1 poster)
- Naval Postgraduate School (1poster)

2. American Society of Engineering Education, 118TH Annual Conference & Exposition. Vancouver B.C. Canada. June 26-29, 2011

- Fostering Systems Engineering Education through Interdisciplinary Programs and Graduate Capstone Projects. Jacques, David (Air Force Institute of Technology)
- Integration of Systems Engineering Training Modules into Capstone Courses across College of Engineering Departments. Ellis, Darin (Wayne State)
- SE Capstone: Experimental Learning in Distributed Classroom Environment for Systems Engineering Capstone Projects. Corns, Steve(Missouri University)
- SE Capstone: Introducing Multidisciplinary Capstone Design to the United States Coast Guard Academy. Adrezin, Ronald (US Coast Guard Academy)
- SE Capstone: Implementing a Systems Engineering Framework for Multidisciplinary Capstone Design. Sheppard, Keith (Stevens Institute)
- SE Capstone: Introduction of Systems Engineering into an Undergraduate Multidisciplinary Capstone Course. Nemes, James (Penn State)
- SE Capstone: A Pilot Study of 14 Universities to Explore SE Learning and Career Interest through DoD Problems. McGrath, B., Lowes, S., Squires, A., Jurado, C.

3. 2011 IEEE Systems and Information Engineering Design Symposium. Charlottesville, Virginia. April 29, 2011

- A Systems Engineering Approach to Micro Expression Facial Motion Capture with Structured Light. Bruner W., Chakravarthy, T., Jones, K., Kendrick, R., LaManna D. (Southern Methodist University)
- Multiple User Motion Capture and Systems Engineering. Colvin, C., Babcock, J., Forrest, J., Stuart, C., Tonnemacher, M., Wang, W. (Southern Methodist University)
- The Design of a Portable and Deployable Solar Energy System for Deployed Military Applications. Tyner, J., Coates, M., Holloway, D., Goldsmith, Daniels, C., Vranicar, T., Roling, J., Jensen, D., Mundy, A., Peterson, B. (US Air Force Academy)
- Rapid Adaptive Needs Assessment (RANA) Water Quality Kit. Barham, S., Kazlauskas, S., Reynolds, R., Tabacca, J., Verrilli, E., Zhang, K., Harrison, P., Mathew, M., Louis, G. (U of Virginia)

- Hand Tracking and Visualization in a Virtual Reality Simulation. Cameron, C., DiValentin, L., Manaktala, R., McElhaney, A., Nostrand, C., Quinlan, O., Sharpe, L., Slagle, A., Wood, C., Zheng, Y., and Gerling, G. (U of Virginia)

- Using Electroactive Polymers to Simulate the Sense of Light Touch and Vibration in a Virtual Reality Environment. Cameron, C., DiValentin, L., Manaktala, R., McElhaney, A., Nostrand, C., Quinlan, O., Sharpe, L., Slagle, A., Wood, C., Zheng, Y., and Gerling, G (U of Virginia)

4. CDIO, 7th International Conference. Copenhagen, Denmark. June 20-23, 2011

    - System Engineering in Senior Design Capstone Projects. Rudd, K., Waters, J., O'Mara, C., Flaherty, C., Janssen, M. (US Naval Academy)

5. International Council of Systems Engineering, 21st Annual Symposium. Denver, Colorado. June 20-23, 2011

    - Panel: Integrating Systems Engineering into Engineering Curricula through Capstone Projects. Beth McGrath, James Nemes, David Olwell, David Umphress.

6. McGrath, E., Nemes, J., Olwell, D., & Umphress, D. (2011). Integrating Systems Engineering into Engineering Curricula through Capstone Projects. INCOSE Insight, September 2011 – Volume 14 Issue 3. pp. 23-24

7. Green Expeditionary Housing in DOE Competition
   The Stevens SE Capstone project was leveraged for the creation of another large-scale, interdisciplinary project addressing sustainable building and energy. In the U.S. Department of Energy **Solar Decathlon 2011** competition, Stevens partnered with the New School - Parsons School of Design and Habitat for Humanity as one of 20 international finalists. The systems engineering approach of the SE Capstone project was evident in this entry to the competition, which won top honors in the "Affordability" competition.

4.2 COURSE STRUCTURES, MATERIALS AND INTERNAL ASSESSMENTS

A variety of methods, approaches and structures were employed in the implementation of the courses. Appendix A summarizes the differences in type of student (graduate/ undergraduate/mix), course integration, and DoD problem area. Eleven SE Capstone institutions provided course materials in the form of lecture notes, PowerPoint slides, reference materials, and related artifacts to the central project repository (the Sakai web site). Some of these materials were created expressly for the SE Capstone course, while others were adapted/modified from existing course materials. The collection of materials can be found at each partner institution's Sakai Work-Site (resources tool) in the following location:

Folder: RT19 2010-2011

Sub-folder: Course Material

The other three institutions (NPS, Naval Academy, and USCGA) did not provide course materials, but provided course syllabi in this folder.

A review of the course materials yielded the following main themes of the various SE Capstone course implementations:

1. Teaching methodologies to deliver systems engineering principles and methods-There are 4 different methodologies identified: (1) conventional lectures to deliver exclusively SE fundamentals, (2) SE fundamentals integrated simultaneously within the implementation of projects, (3) Intensive all-day SE workshops, (4) SE content included in pre-existing courses.

2. Standards-The spectrum of stakeholders includes not only clients but also regulatory bodies, groups of interest, etc. Many times overlooking the diverse character of stakeholders has been a main factor on failing to deliver products; hence, making students aware of the importance to comply with safety, environmental and other type of standards is helpful for them to understand all constraints involved in real world complex projects.

3. Course Management Systems [virtual learning environment]-Course management systems used as global repository for coursework materials contributes to improve students' organizational skills, which are indispensable for well qualified systems engineers.

4. SE Software applications-Most of systems engineering principles are abstract; therefore, software applications to visualize systems architecture [functional and physical view] and integration become indeed an invaluable productivity tool. Also simulation/decision-making packages are important for controlling cost-schedule-quality [trade-offs].

5. Archive of recorded lectures-This feature is remarkably effective to enhance learning on any field of knowledge, providing students with the opportunity to get a better understanding of what is being taught in the classroom by eliminating the burden of constantly taking notes as they can always review the video recorded lectures from the archives

Appendix B includes a chart delineating the course materials developed/used by each institution and the corresponding student deliverables and internal assessments.

4.3 ONLINE REPOSITORY: SAKAI

In order to manage the large number of documents disseminated and collected by RT-19 stakeholders, the research team created a password-protected, online document and media sharing repository using the Sakai content management system. Sakai is a private collaborative website with a broad range of functionalities such as Messages, Announcements, Blogs, Resources (file sharing) intended to facilitate electronic document storage and online collaboration. This tool was necessary to provide access to documents, assessments, archived WebEx recordings of project information, report templates, and other documentation, to a variety of constituencies, including faculty from 14 institutions, sponsor contacts, and others. The tool was also intended as a way to facilitate communication and sharing of resources and lessons learned among PIs and RT-19 faculty, as each institution was allocated its own work site and file location to upload private and shared resources.

Figure 17: Sakai - Private Collaborative Website

In addition, students of most institutions used the blogging tool as the vehicle for their weekly updates on project progress. Later on, the blogs were suggested as a vehicle to facilitate the communication between students and DoD/Industry mentors which was an additional application of this tool. Access to the Partner Institution Work-Sites was restricted to the ASDR&E representatives and the research team in order to ensure compliance with IRBs and intellectual property protections.

Shared work-sites were created to facilitate the dissemination of information. These included.

1. *Project News*. Used for status updates. The tools mostly used were: announcements, messages, and resources which served as a repository for all online meetings (WebEx sessions) and corresponding materials, e.g. PowerPoint slides.
2. *Publications & Dissemination.* Papers authored by PIs and The Research Team presented at different conferences and symposiums were collected and gathered in this work-site.

3. *Assessments.* Used by the Research Team to post materials related to the implementation of common assessments.
4. *July 2011 Workshop*. Although initially set up to facilitate the planning of the RT19/RT19A workshop (held in Washington DC), this work-site also compiles student products such as posters and videos showing prototypes demos.
5. *DoD Problem Areas*. In August 2010, an official RT19 kick off meeting was held in Washington DC where a group of DoD experts offered briefings on the focus areas of DoD interest. All presentation materials were collected on this work-site to serve as guidance for PIs of all partner institutions.
6. *IRB*. Where materials related to SERC-Stevens IRB approval were uploaded.

Functionalities such as Announcements, Messages, and Resources (for file sharing) made Sakai a valuable project management tool for the implementation of RT19. Written and screencast tutorials on the use of Sakai for project needs were developed and made available to all SE Capstone Teams. The blogging tool was envisioned as the default location for students' weekly posts, to prove ease of use for the research team to monitor this qualitative assessment. Although the goal was to empower the many users from a variety of organizations to independently access Sakai to locate and upload materials, and enter blog posts, a great deal of technical support and facilitation was necessary from the start of the project to the collection of PI's final reports.

As with the introduction of any new tool, a learning curve and ease of use curve will precede habitual use. Sakai, or other online repositories like it, have the potential to serve as an online collaboration tool for RT-19/RT-19A and future SE Capstone participants to share and disseminate lessons learned.

Similarly, the WebEx videoconference meetings were held periodically (roughly monthly) to disseminate project information, showcase exemplars, and answer questions. Archived recordings were posted on Sakai to enable faculty to refer back as needed.

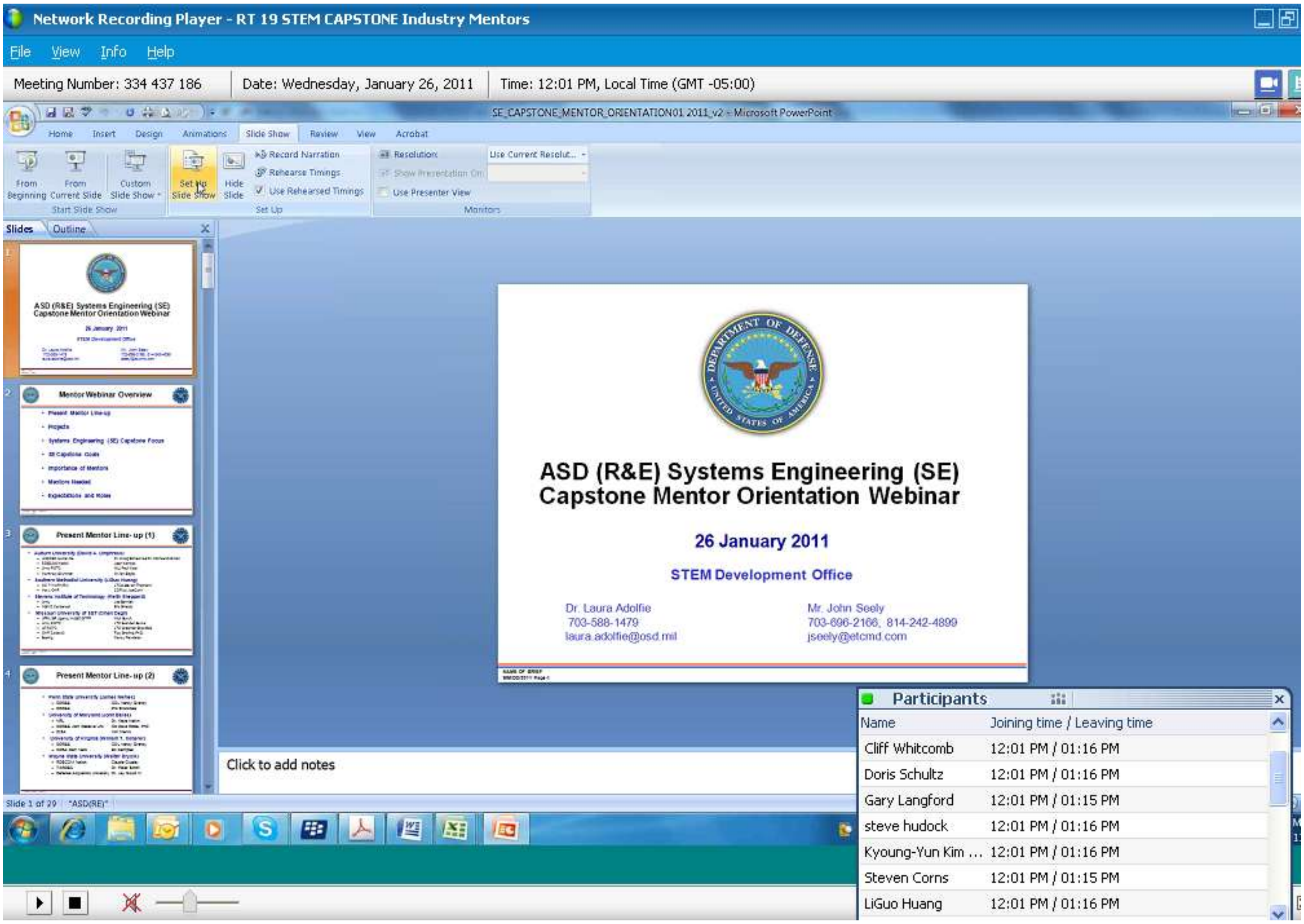

Figure 18: WebEx - Videoconferencing Software Application

During spring 2011, ASDR&E representatives conducted site visits to all but one RT-19 partner institution[13]. They identified a set of nine promising practices—approaches which were present in universities where the site team reported that students demonstrated ”improved communication and awareness of the systems engineering process…where they used a different [i.e., more sophisticated] vocabulary to describe their work…and where their understanding of domain specificity and its contribution to the system were [evident]”—and presented them at Panel Session 1 during the July 11-13, 2011, workshop (McGrath, Ardis, Lowes, Lam, & Jurado, 2011). These promising practices therefore described the conditions or course characteristics which may have contributed to or were present in institutions which produced students who possessed the types of professional SE knowledge and skills which aligned with DoD’s explicit or implicit needs, as observed by the DoD visiting team.

Bransford, Brown & Cocking give credence to experts’ ability to notice features and identify “meaningful patterns of information that are not noticed by novices,” and state that, “experts have acquired extensive knowledge that affects what they notice and how they organize, represent, and interpret information in their environment …” Further, they note that, “Experts’ knowledge … reflects contexts of applicability: that is, the knowledge is “conditionalized” on a set of circumstances” (Commitee on Developments in the Science of Learning, 2000, p. 31) .

The promising practices noted by the ASDR&E visiting team of experts, with additional comments from the ensuing conference discussion, are as follows:

1. <u>Two-semester course sequence.</u>

   Fall semester tools/ techniques/ approaches SE theory course, followed by spring semester design project course. Fall course should present balance of “traditional” SE approaches with automated tools/ models/ simulation techniques.

2. <u>Cross-disciplinary faculty and multi-disciplinary student teams.</u>

   These provide the best experience for students. However, expectations of SE competencies (depth of knowledge/skill development) should be different for undergraduates vs. graduates. From the student perspective, the "real life experience" (e.g., communication, working with people from different backgrounds) is critical.

3. <u>Regular, direct involvement of mentors with student project teams</u>.

   These should be significant face-to-face meetings (i.e., twice monthly) with “on-call” consultations between meetings—both for to help with the engineering process and to help foster SE career awareness and an appreciation for systems engineering.

4. <u>Established relationships with nearby DoD commands and facilities.</u>

[13] The ASDR&E team did not visit Penn State University, which had completed its fall semester course by that point.

5. Creative use of mentors from defense industry contractors and/or DoD representative.
   Some institutions had built-in relationships, either through past PI industry or military experience, or had connections to other military institutions. ROTC involvement where possible

6. Structured design reviews with DoD and industry mentors serving as reviewers.

7. Use of SE Ph.D. candidates/advanced graduate students as project advisors.

8. Creative imposition of technical, budget, and schedule constraints by faculty to model "real world". In addition, physical prototypes are considered important for student motivation, in order to demonstrate products for DoD sponsors, and in order to begin to pipeline projects to more advanced testing. Prototypes illustrate the tradeoffs made during the design process. Both software and "hardware" prototypes are acceptable, including decision-making software.

9. For civilian institutions that have on-campus ROTC units, established relationships with ROTC units for requirements analysis, use case testing, and solution viability.

These promising practices were implemented to varying degrees in the RT-19 project. A graphical representation of the presence (or lack thereof) appears as Appendix E. Here we discuss them in greater detail:

Two-semester sequence: theory then practice:

All but three of the RT-19 participating institutions included the two-course sequence, with two (PSU and UMD) implementing single semester Capstone courses and one (NPS) encompassing multiple semesters.

Those PIs who advocated for the two-semester sequence felt that they needed the first semester to introduce the techniques and practices of systems engineering to students from other engineering disciplines and felt that traditional classroom presentation and homework were effective for this purpose. In addition, although software packages for simulation and modeling, project management, and system architecture were valuable tools for developing an appropriate concept of operations that can be effectively tested through implementation of real projects, the students need time to learn them well enough to use them effectively. The differences lay in when the project work was introduced. For example, Stevens followed a two-course sequence heavily focused on project work and design, with "just in time" learning about SE competencies interspersed throughout. Other schools followed the more traditional sequence. Where project planning did not begin early enough, students reported struggling with the timely acquisition of the necessary resources.

Cross-disciplinary faculty and multi-disciplinary student teams:

Most systems engineering projects span multiple engineering disciplines and both faculty and students reported that the multi-disciplinary nature of the projects was challenging but also yielded more realistic experiences. Many students wrote that they had learned about the difficulties of managing interdisciplinary teams, thus experiencing some of the same challenges practicing engineers face when

working on real-world, multi-disciplinary projects. At the same time, students ranked team members from other areas almost as highly as team members from their own disciplines in terms of their perceived usefulness. In addition, those groups that lacked sufficient expertise from other disciplines wrote about how they had suffered as a result.

Almost all of the other schools had some element of multi-discipline participation, but the teams from Stevens Institute and the University of Virginia had particularly large and diverse teams. It is notable that students at both institutions rated their projects as highly successful.

Regular involvement of mentors:

Mentors played a key role in many of the student projects. They provide needed practical experience, and they help students appreciate the value of their project contributions. All SE Capstone partner institutions had at least one DoD mentor, and about half had additional mentors. In some cases mentors visited their student teams multiple times during the project, but regular contact at least via teleconference was important. Mentors who served as clients facilitated the creation of a needs statement and helped teams derive stakeholder requirements, emulating a systems engineering approach in real world conditions. Also, PIs reported that mentor participation in design reviews was particularly effective for validation of the process. Teams without regular and frequent contact from DoD and industry mentors were, in some cases, frustrated by their lack of involvement and in one case, misinterpreted direction.

Established relationships with nearby DoD commands and facilities:

In some cases student projects were able to exploit their proximity to DoD facilities. These sites provide demonstrable proof of authentic problems and needed solutions and offered opportunities for interaction between students and potential clients and users of their systems.

Creative use of mentors from defense prime contractors:

Defense contractors provide a different point of view from DoD mentors, representing “the solution viewpoint, as opposed to the problem viewpoint of DoD sponsors.” In some cases, contractors were able to “save student teams from exploring too many blind alleys as they have often explored similar design spaces in their work.” In other cases, mentors played multiple roles, as clients and as subject matter experts, although this was not always a successful combination.

Structured design reviews with DoD and industry mentors:

Reviews by external experts are useful in all engineering disciplines. They are particularly helpful to student teams, and in RT-19 they provided a level of experience that faculty sometimes lacked. In their most ideal implementation, these reviews were practiced iteratively, with opportunities for students to learn from previous mistakes.

Some schools, such as the Military Academy, taught structured design reviews early in their curriculum, with opportunities to practice them in several courses. Other institutions taught them as part of their Capstone experience. Students who had more experience with the process before their Capstone courses were better able to focus on technical details during the reviews.

Use of SE graduate students as project advisors:

In some cases graduate students were very effective advisors of undergraduate student teams. Although graduate students have less experience than faculty, they are closer to the undergraduates in age and culture. This proximity helped in detecting communication problems and provided another channel for student teams to raise concerns.

Creative imposition of technical, budget, and schedule constraints and use of physical prototypes:

Successful systems engineering projects must satisfy *all* their constraints. It is easy for students to lose sight of this when they are in the heat of solving a particular problem. Several student teams dealt with budget constraints in ordering materials for prototypes. In some cases they had to work through standard acquisition processes, with several layers of approvals that delayed the process. In other cases they found ingenious ways to circumvent spending limits by breaking purchases into separate transactions and bargaining with suppliers. Exposing students to a broad range of constraints helps them attain a more holistic view of systems engineering. As far as the need to build physical prototypes, this was clearly important to the students, who felt their projects were successful even if the prototype was not complete.

Relationship with ROTC units:

ROTC units provided some of the context and expertise advantages discussed earlier for nearby DoD facilities. For instance, ROTC units are sources of potential stakeholders (e.g. reservists) needed for development and testing of use case scenarios.

These promising practices have guided the selection and characteristics of the next phase of research being pursued in RT-19A (Pilot for Scaling Up and Sustaining Effective SE Capstone Practices) and their presence and degree will be examined more closely during that project, both in terms of varieties of implementation and correlations, if any, to intended student outcomes.

6.0 FINDINGS AND RECOMMENDATIONS

RT-19, *Research on Building Education & Workforce Capacity in Systems Engineering,* was conceptualized and designed as a pilot study to develop a better understanding of the impact of differing course designs, structures, materials, instructional practices, and other inputs, such as the involvement of DoD and industry mentors, on student learning and career interest in systems engineering. After a competitive selection process, 14 institutions, both civilian and military, developed and enhanced courses configured in a variety of ways, but which all encompassed key characteristics: an integrative, project-based capstone course in which students worked in teams, interacted with clients external to their academic institution, and practiced systems engineering in the development and design of physical prototypes to address one of a given set of authentic, motivating DoD problems.

The overarching goal of the research was to help inform the sponsor about making future investments in Systems Engineering Capstone courses in a nationwide scale up effort, e.g., what methods and approaches lead to greater student learning gains and greater SE career interest, particularly interest in DoD problems and careers. In addition, there were three research questions centered on student outcomes: student learning of systems engineering; student interest in SE careers; and student awareness and interest in authentic DoD problems. The mixed methods approach aimed to gather pre- and post-course data from students at all participating institutions with the goal of correlating higher levels of student outcomes with the course characteristics that produced those outcomes.

A vast amount of data was collected, both the data anticipated from students, as well as data from PI reports, sponsor site visit teams, a July culminating workshop, papers, posters and presentations by faculty and students, and "performance assessment data," in the form of student prototypes and accomplishments in a variety of student competitions. Due to several factors, including (a) small sets of matched pre-/post student responses at several institutions, making statistically valid correlations difficult; (b) the variety of metrics of student success, including those we set out to assess (definitional learning, growth in depth of analysis of a case study using SE knowledge, and career [and DoD career] interest), as well as those which emerged over the course of the project, e.g., student success in external competitions, prototypes with high potential for transition to near-term military use; and (c) the multiplicity of variables (problem area selected, graduate vs. undergraduate vs. mixed student populations, duration of course, participation of mentors, and others), it was not possible to correlate specific university (or course) characteristics with student success. However, even though the data are not as complete as the research team would have liked[14] ; it is possible to draw some general conclusions from the results.

[14] Compliance by all institutions with the requirement to administer the three mandatory, "common" assessments pre- and post-course to all students was hampered by several factors: (1) staggered start and end dates of SE Capstone courses among the 14 institutions; (2) lack of post-course data for two institutions (NPS and Wayne State); (3) entry and exit of new students in the second semester; (4) competing end-of-course demands, including participation in external competitions, on faculty and students.

The analysis of student definitions of systems engineering showed that the participating students were able to use general systems engineering terminology almost as well as experts but that they still had some way to go in employing more technical systems engineering language. However, those with the most to learn—undergraduates and those with no prior system engineering experience—improved the most, particularly in terms of technical language. In addition, the analysis of the Bradley Fighting Vehicle case study showed that students increased in their ability to identify problems that mapped to specific systems engineering competencies, particularly those related to the technical elements, but that they were less likely to mention the "soft" competencies like communication and leadership. The blogs, where used well, showed students working through the phases of the design process and struggling with various technical and communication issues along the way.

It was abundantly clear that students enjoyed the real-world nature of the projects—both in terms of building an artifact that might be used and in terms of the SE project context (budget constraints, interdisciplinary teams, experts as mentor)—and that they appreciated the contribution that the systems engineering perspective brought to their work. Although these courses do not appear to have had a major impact on the students' immediate career plans, it must be noted that many had their immediate post-college plans in place and that a large majority of both undergraduates and graduate students believed that they might choose careers in systems engineering sometime in the future.

Given the student results described in earlier sections and summarized above, the set of promising practices as described in Section 5, and the original goal of developing a set of recommended models to be scaled up in engineering institutions across the U.S. to address the current and projected shortage of SE talent for DoD and industry workforce needs, our recommendations for future implementations and future study include:

1. Develop a methodology to prioritize and rank the student attributes and outcomes most likely to meet DoD and defense industry needs in the near term (0-5 years) and longer term. Consider attributes such as increased learning of SE; increased interest in DoD problems; increased interest in/commitment to DoD careers; production of a prototype with high potential for military use; student success in SE competitions; potential for recruitment to DoD of declared SE graduate students vs. the undergraduate engineers with less SE knowledge/experience, etc. Such a ranking/prioritization will allow more specific targeting of resources into those programs that produce those high priority outcomes.
2. Examine the presence, depth, and characteristics of implementation of the promising practices through case study analysis (a component of research included in RT-19A); correlate, where possible, to the highest priority student attributes described in (1), above.
3. Distill the attributes of effective DoD and industry mentor relationships through further analysis of "what worked" and what did not. Investigate the incentives and rewards for mentors to continue involvement with university partners. Qualitative data suggest that features of effective mentoring relationships include: clear boundaries between the roles of clients and technical advisors; engagement in frequent, iterative, face-to-face communication, and who see benefit in the development of long-term relationships with universities for their own recruitment, research, and

other needs. Consider regional and national events followed, possibly, by online networking to identify new mentors.

4. In coursework and in DoD mentor communications, make very explicit the goal of attracting students to DoD careers in systems engineering. It cannot be assumed that students will understand the variety of careers and options available to them based on the one project they work on. The DoD mentor undoubtedly plays a large role in illustrating that the DoD has competent engineers with important assignments, but a single individual focused on a specific project cannot be expected to showcase the career opportunities and the wide range of problem areas available for students upon graduation. Consider providing a “tip sheet” or online training for mentors to prepare them—and faculty—to assist in communicating the opportunities available for SE careers within DoD.
5. Leverage the experience and expertise of the RT-19 and RT-19A to build and expand a learning community of SE Capstone stakeholders (engineering institutions, clients, and mentors) through: a public web site and publication describing SE Capstone courses, products, partners, and models and support/encouragement of academic dissemination at national forums attended by potential new scale up partner institutions.
6. Consider piloting new approaches to sustain the SE Capstone project, including the creation of an online repository of potential DoD problem areas and clients along with a “venture fund” that would provide small grants of $5,000-$10,000 for materials and access to DoD problems and clients for institutions that already organize Capstone projects.
7. Publicize in relevant professional journals, education media, and the general media the contributions of SE Capstone design teams to the development of solutions critical for our military and our nation’s security.
8. Conduct a longer-term study (1-5 years) tracking RT-19 participants and their career choices and employment trends.

7.0 ANALYSIS OF FINANCIAL EXPENDITURES

The final expenditure report will be issued by the SERC Director of Operations separately, upon completion of processing of all pending transactions. However, as of October, 2011, the following represents the major expenditure categories and expenses in the aggregate as of the current date**.**

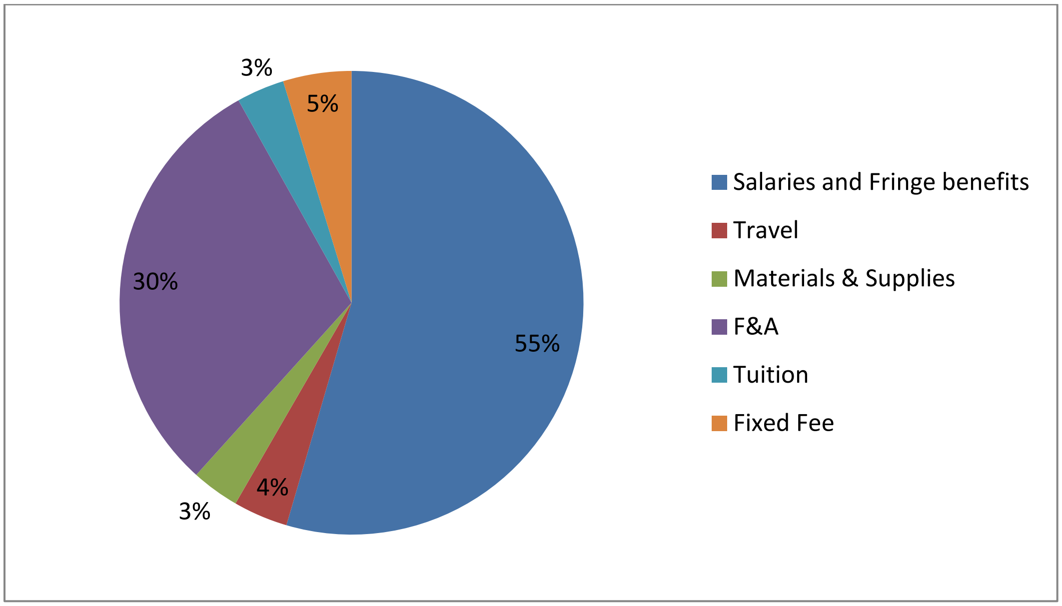

Figure 19: Financial Expenditures

8.0 CONCLUSIONS, NEXT STEPS, AND FUTURE RESEARCH

RT-19 launched an ambitious and dynamic experiment to better understand academic models that could lead to the generation of SE talent for DoD and industry needs. More than 360 undergraduate and graduate engineering and related students were exposed to four broad, DoD problem areas. Seventeen entries in student competitions such as NDIA, IEEE/SIEDS and the Solar Decathlon resulted from RT-19 student projects. Twenty-six papers and conference presentations were published/presented based on RT-19 research. SE Capstone courses positively impacted, to varying degrees, student learning of SE capstone competencies, their interest in SE careers, and their interest in DoD problems.

As this project was undertaken as a pilot to prepare for a larger scale up effort, a proposal for a national scale up was developed in early 2011. However, due to budget uncertainties related to the Continuing Budget Resolution, a small-scale scale-up effort was launched, which includes 11 returning RT-19 institutions and six new partners, chosen to collaborate with, and learn from, the first cohort. The new project (RT-19A) builds upon lessons learned from the pilot:

- All institutions conduct the SE Capstone courses over at least two semesters, with many starting their student projects earlier than they did during RT-19
- Strong mentorship programs will be used to guide and motivate students
- Students will not be required to keep blogs, but other forms of social networking between schools and students will be investigated
- A simpler mechanism for assigning identifiers to students on pre-/post student surveys will be used to ensure that more responses can be correlated.

An important goal of the RT-19A is to discover best practices for bootstrapping new systems engineering capstone experiences at institutions that do not already have them. In particular, partnering arrangements between institutions are being implemented and studied as one approach to scaling up.

In addition to the final report, two additional products are planned:

- A public Systems Engineering Capstone web site for informational and document/artifact-sharing purposes to a range of audiences, including DoD sponsors, returning and new mentors, other federal agencies, universities seeking to replicate effective SE Capstone courses and practices, and others. A login feature will provide password-protected access to confidential areas of the site for the RT-19/RT-19A community.
- A glossy brochure including photos of student teams and artifacts summarizing highlights of RT-19 findings, lessons learned, exemplars, and opportunities for collaboration.

Additional avenues (e.g. Facebook Page) to foster cross-collaboration among students are also being considered. In RT-19A, the research team will promote collaboration among PIs, and the use of tools such as wikis will be considered for increased collaboration among PIs, mentors, and other stakeholders.

Appendix A: Course Structure and Foci

School	Course/Project	Description	DoD Focus	#Students
Auburn University	Systems Engineering in a Secure Computing Intensive Environment	1st course [Fall 2010] is a broad-spectrum overview to systems engineering. It introduces major concepts using a case study of the security architecture of two open systems under consideration by DoD. 2nd course [Spring 2011] is an actual project employing low-cost, open-source, secure computing. The students demonstrate secure collaboration using The Android open source software stack.	Improvement of computer systems to enable secure data sharing among complex systems at low cost. Course material for the 1st course delivered through presentations by speakers from industry and government; lectures, and interactive students activities. The 2nd course is a hands on sequel In which students l complete their Defense-focused capstone project	Fall'10: 33 Spring'11: 17 Mix of CS, IE, And EE On-campus And distance education
Missouri S&T University	Agile Systems Engineering-Active And Experiential Learning Approach	1st Course [Fall2010]: Introduction to Systems Engineering provides the student with basic understanding of main concepts, tools, and processes of systems engineering. 2nd Course [Spring2011]: Physical Artifact Creation and Validation. Development of detailed design for a wireless haptic vest with embedded sensors. Students focused on the wireless tech to activate embedded sensors and mechanical components	Immersive Training Technologies. Subtle simulation of real battlefield scenarios. Operational scenarios simulate getting shot, getting hit, and minor restriction.	Fall'10: 30 Spring'11: 30 Mix of ECE, ME, and AE On-campus and distance education
Penn State University	Interdisciplinary Capstone Design Project	This is a one-semester course/project [Fall2010]. Eight modules delivered by systems engineering faculty. Projects are completed using the Bernard	Expeditionary Assistance Kit. 1. Water purification system 2. Power generation from renewable energy sources 3. Local situational awareness	Fall'10: 17 Mix of BE, CE, EE, ME, IE

		M. Gordon Learning Factory, a lab providing modern design, prototyping, and manufacturing facilities.	system 4. Global low-bandwidth communication unit	
School	Course/Project	Description	DoD Focus	#Students
Southern Methodist University	Leveraging Interdisciplinary Teaching Environments to Research Immersive Training Environments	1st Course [Fall2010], students work in interdisciplinary teams to design an architecture solution that meets customer specifications. **Winter break: 10 days Skunk Works Immersion Design Experience. (IDE)** 2nd Course [Spring 2011], students continue to work on interdisciplinary teams to build and test a prototype of their design.	Immersive Training. The objective is to improve existing capabilities in three areas: (1) fidelity of motion capture systems, (2) reduction of infrastructure required for team based motion capture, and (3) high resolution facial expression capture and replication	Fall'10: 75 Spring'11: 11 Mix of CS, EE. and ME . 3 PhD students acting as TAs
Stevens Institute of Technology	Building Education and Workforce Capacity in Systems Engineering through Capstone Design	Implementation of SE in capstone senior design course [one year long] A series of Systems Engineering all-day workshops delivered to introduce SE principles and methods to all students. Capstone project starts in Spring 2011.	Green-Expeditionary Housing. For a 100 person FOB and 3-6 months deployment. Modular housing with micro-grid support for alternate energy sources, including low impact solutions for waste and water	Fall'10: 24 Spring'11: 19 Mix of EM, ME, EE, CE, Civ Eng, A&T
University of Maryland	Special Topics in Systems Engineering	This is a one semester course that is offered twice over one academic year. The goal of this pilot is to introduce students to SE through hands on project experience. [4 grad students providing assistance to undergrads]	Focuses on low-cost, low-power computers leveraging open source technologies. Supports integrated wireless sensor networks, black box design, smart tire system, border security.	Fall'10: 15 Spring'11: 37 Mix of EE, CE, BE.
University of Virginia	Extensible Systems Engineering Capstone Experience	It exposes students to the entire systems engineering process. This will be accomplished via two interdisciplinary capstone projects over one academic year. During the 2nd semester the two teams will	Project #1: involves a virtual reality system for medical training. Project #2: This project is focused on developing a mobile, autonomous,	Fall'10: 17 Spring'11: 16 Mix of SE, ME, CS, BE, ECE

		test and evaluate each other's projects. 2 SE grad students [providing technical support]	water quality testing system.	

School	Course/Project	Description	DoD Focus	#Students
Wayne State University	Integrated Material Design and Realization for HA/DR Kits	This project integrates SE product development concepts across 4 courses at the undergrad and graduate level. 1 Full semester course (Winter 2011) plus modular insertion into multiple other courses (start process – Sept 2010)	Expeditionary Operations. The projects focused on development of elements of HA/DR kits, such as solar oven, water purification system, alternative energy	Fall'10: 29 Spring'11: 16 Mix of ME, ISE
AFIT [Air Force Institute of Technology]	Introduction to Systems Engineering Process and Design	This course [one academic year] provides a broad introduction to a systematic approach necessary for the formulation, analysis, design and evaluation of complex systems. Technical support provided by the Autonomous Navigation Technology Center associated with the Department of Electrical and Computer Engineering	Low-power computing for operations in austere environments. Development of a novel hybrid electric UAV for near silent, long loiter, low energy operations.	Fall'10: 5 Spring'11: 5 Mix of AE, SE
NPS [Naval Postgraduate School]	Transforming Graduate Education in Systems Engineering	A series of 8 core SE courses [one academic year]in the masters curriculum are being taught in a faculty team based pedagogy, with the capstone project integrated into the entire curriculum as a carry through, hands on experience. The courses provide a holistic span of education from systems thinking, , quantitative analysis, through system design and production	Expeditionary Operations and HA/DR Assistance Kits. Development of novel, low density power supplies, advanced materials with low thermal and visibility properties, low signature communication devices. [project starts in January 2011]	Fall'10: 38 Spring'11: 38 SE

USAFA [Air Force Academy]	Capstone Design Project	This project integrates sequentially two SE courses over one academic year. Students learn to successfully work in a multidisciplinary team, to apply SE and management tools, communicate project details, and evaluate contemporary military issues	Low Power Computing A 10 KVA solar energy system for deployed operations. The end system incorporates smart grid technology to facilitate control and integration [project starts in Spring'11 semester]	Fall'10: 7 Spring'11: 7 Mix of EE, CE, ME, SE

School	Course/Project	Description	DoD Focus	#Students
USNA [Naval Academy]	Principles of Engineering Systems Design	The senior design capstone course [one academic year] is enhanced with additional SE sections based on experimental coursework. This is an independent study course based on Defense Acquisition University courses	Expeditionary Ops. Portable, low power water purification. Portable, renewable power generation, storage and distribution [most of the project-centric work is done in the spring semester]	Fall'10: 16 Spring'11: 16 Mix of EE, CE, NA, OE
USMA [West Point]	Systems and Engineering Management Design	This capstone course [two sequential courses over one academic year] emphasizes SE in technology based organizations. Cadets examine interconnections between planning, organizing, leadership, control, and the human element in production, research and service organizations	Immersive Training Augmented Reality: synthetic environ, decision analysis for optical & video displays, high fidelity tracking	Fall'10: 4 Spring'11: 4 Mix of SE, EM, and OR
USCGA [Coast Guard Academy]	Systems Engineering Capstone Enhancement	This senior design capstone course [one academic year] incorporates critical elements of systems engineering	Expeditionary Ops. Green Power Generation HA/DR Portable hull inspection system. Green electric power in remote hot	Fall'10: 20 Spring'11: 24

		Cadets must defend their work at preliminary and final design reviews	climates. In water remote propeller cleaner. Hybridization system for fleet vehicles.	Mix of Civ Eng, EE, and ME

NOTES:

1. Sources include proposal documents submitted by universities, interim and final reports, and a summary prepared by R. McGahern for a presentation at the 2010 Annual SERC Research Review conference Nov. 9-10, 2010.
2. The number of students shown in the table above include only those who are directly involved in the whole capstone experience [coursework +project].
3. Abbreviations :
   EM: engineering management, CE: computer engineering, Civ Eng: civil engineering, EE: electrical engineering, NA: naval architecture, OE: ocean engineering, AE: aerospace engineering, A&T: arts and technology, OR: operations research, IE: industrial engineering, ME: mechanical engineering, CS: computer science, SE: systems engineering, BE: biomedical engineering, ECE: electrical and computing engineering, ISE: Industrial & Systems Engineering

Appendix B: Course Materials/Student Deliverables/Internal Assessments

School	Course Materials	Student Deliverables	Internal Assessments
Auburn University	**SE Lecture topics**: conceptual design, preliminary design, detail design, testing, open Source computing systems, acquisition, security certification, systems security, decision analysis, configuration management, economics, real world systems engineering. **Standards**: National Information Assurance Training Standard for Senior Systems Managers. **Course management system:** Blackboard™ **Software applications**: I-CAIV [decision analysis], Eclipse & Papirus [SysML diagram] **Archive of video recorded lectures** [for students viewing]	Initial project idea, status reports, preliminary detailed design presentations, evaluation reports, final project	formative assessments, case study, mid-term and final exams
	SE Lecture topics: system definition and concepts, requirements and specifications, dynamic object-oriented requirements system	Fall'10: full set of requirements, functional analysis, cost estimate,	

Missouri S&T University	[DOORS] presented by BOEING mentor, functional analysis and decomposition, quality function deployment [QFD], conceptual systems design, DoD architecture framework, risk identification/management, Sys Eng planning , architecture evaluation, manufacturing and disposability, supportability, economic evaluation, preliminary design review, reliability, system test and evaluation, trade off studies, modeling and simulation, detail design, optimization in design and operations, writing specifications. **Course management system:** Blackboard™, WebEx	work breakdown structure, risk assessment, technical management plan, system physical architecture, specifications. Spring'11: DOORs database, interface document, MOEs/TPMs/Attribute document, scenario and integration testing document, system validation	Presentations performed for mock reviews. Components of the final written project document were assignments to evaluate progress
Penn State University	**SE Lecture topics:** systems engineering fundamentals, systems requirements analysis and allocation, systems architecture, problem solving in system design, decision and risk analysis, introduction to project management, systems verification and validation, introduction to systems thinking **Reference material:** NASA Systems Engineering Handbook, 2007 **Course management system:** ANGEL [Penn State Management System]	System requirements document, architecture design document, conceptual design review, verification & validation plan, risk mitigation plan, preliminary design report, critical design review.	pre-post surveys, case study
School	Course Materials	Student Deliverables	Internal Assessments
Stevens Institute of Technology	All day workshops to introduce students to key SE principles and methods. System level architecture, subsystem level architecture, logistics and life cycle support, subsystem integration and test, system level integration test. NOTE: Just the 1st workshop was conducted as planned. The rest of topics were injected in an ad-hoc and informal way throughout the semester. **Course Management System:** Google Groups, Google Docs, Dropbox **SE Software applications:** Labview, Solidworks	ConOps document including overall problem analysis, key requirements, operational scenarios, concepts for key sub-systems. Camp performance simulations. Budget spreadsheets. Presentations.	interim reports, presentations, surveys, rubric to assess SE competencies

University of Maryland	**SE Lecture topics:** introduction to systems engineering, strategies of SE development, foundations for model-based systems engineering, modeling system structure and system behavior, object and component based development, multi-objective trade studies, requirements engineering, systems engineering with UML and SysML [Sandy Friedenthal from Lockheed Martin delivered a special lecture on SysML, which was recorded], system level design, basic approaches to system validation/verification, basic approaches to system validation/verification. **Course management system:** UMD's Institute for Systems Research-Website **SE software applications:** ParaMagic™ v16.6 sp1, Matlab/simulink		Lab assignments, instructors' observations, final project presentations.

School	Course Materials	Student Deliverables	Internal Assessments
Wayne State University	**Lecture topics**: introduction to systems engineering, concept evaluation and selection, risk management in design The above SE principles and methods are complemented with the following courses: 1. Integrated Product Development – to educate students about the importance of concurrent and collaborative engineering in a global economy. 2. Thermal-Fluid System Design – with emphasis on alternative energy tech **Course management system:** Blackboard™		presentations, final reports, SE Student Query, Interview, and Response Tool [SE-SQUIRT]
AFIT [Air Force Institute of Technology]	**Lectures topics**: intro/process overview, conceptual system design and requirements definition, model based SE , utility theory, preliminary system design, detailed design and development, system test, evaluation & validation, reliability, maintainability & supportability, affordability, usability/human system integration. These topics were complemented by 3 case studies **Standards**: DoD5000, JCIDS, DAG **Reference Material:** INCOSE Handbook **Course management system:** Blackboard™ **SE software applications**: Enterprise Architect, LEGO Mind-storm robotics kits	concept definition [ConOps document], architecture development, and requirements traceability	homework assignments, exams, case study discussions, final presentations, final reports

School	Course Materials	Student Deliverables	Internal Assessments
USAFA [Air Force Academy]	**Lectures topics**: Introduction to DFEC Capstone Design Course, Requirements development, planning and scheduling, functional analysis and allocation, risk management. **Course management system**: MS-Sharepoint **Software applications**: MS-Project, Crystal Ball	The course was modeled as an Air Force Acquisition project with students preparing and delivering several presentations at various acquisition milestones(PDR, CDR, SVR, etc)	Course specific rubrics are used at each student presentation (PDR, CDR, SVR, etc)
USMA [West Point]	**Lectures topics**: systems thinking, stakeholder analysis, functional analysis, value modeling, value modeling workshop, in-progress review [IPR], modeling and simulation, VBS2 Lab, O*Net Analysis, alternative generation, solution enhancement. **Course management system**: SharePoint Software applications: VBS2, VenSim.	several in-progress reviews throughout the year, final briefing given to the client, final report	literature review, in-progress reports and briefings, peer evaluation, capstone competition judging rubrics, and technical reports
USCGA [Coast Guard Academy]	**Lectures topics**: design process overview, problem definition and need identification, quality function deployment, concept generation, functional decomposition, evaluation [Pugh's matrix], codes and standards, human factors, design for manufacture, design for assembly & recycling, engineering economics, detail design, engineering ethics, modeling and simulation, risk-reliability-safety, quality-robust design-optimization **Course management system:** Blackboard™ **Software Applications**: Solidworks		assignments, written and oral reports, project advisors evaluation

Abbreviations:

SE: systems engineering, DAU: defense acquisition universities, INCOSE: international council on systems engineering, PDR: preliminary design review, CDR: critical design review, SVR: system verification review.

Appendix C: List of Web-Links to videos of prototype demos

- Auburn University

  http://swemac.cse.eng.auburn.edu/~umphrda/sysEng/RT19/Team1Video.wmv

  http://swemac.cse.eng.auburn.edu/~umphrda/sysEng/RT19/Team2Video.m4v

  http://swemac.cse.eng.auburn.edu/~umphrda/sysEng/RT19/Team3Video.mp4

  http://swemac.cse.eng.auburn.edu/~umphrda/sysEng/RT19/Team4Video.avi

- Missouri S&T

  http://msmovie.mst.edu/public/misc/immersion vest.wmv

- Southern Methodist University

  http://www.youtube.com/watch?v=xoE9y2hjMSA

- Stevens Institute of Technology

  http://www.youtube.com/watch?v=ThYZEw7YNbg

- University of Virginia

  http://www.youtube.com/watch?v=N6dw15marHo&feature=youtu.be

- US Military Academy

  http://vimeo.com/27850108

Appendix D: RT-19 Student and Faculty Posters

Electronic copies of student and faculty posters are posted on the Stevens Sakai project site at the following URL: gateway.stevens.edu/home.html: Proposal & Reports – RT19 2010-2011/RT19 Final Report files

Appendix E: Comparison of Program Components

The following table illustrates the various elements and promising practices present in each of the SE Capstone courses:

APPENDIX E: PROGRAM COMPARISON- Evidence of Promising Practices

CHARACTERISTICS	AFA	AFIT	AUBURN	CGA	MUST	NPS	PSU	SMU	STEVENS	UMD	UVA	WAYNE	USMA	USNA
Type of SE program: Systems Analysis & Design	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	N	Y	N
Type of SE program: Industrial/Manufacturing Engineering	N	N	Y	N	N	N	N	N	N	N	N	N	N	N
Type of SE program: Traditional Control Systems	N	N	N	N	N	N	N	N	N	N	N	N	N	Y
Type of SE program: Control Systems plus other topics	N	N	N	N	N	N	N	N	N	N	N	N	N	N
SE degree offered: Undergraduate degree offered in	Y	N	Y	N	N	N	N	N	N	N	Y	N	Y	Y
SE degree offered: Masters or PhD degree offered in	N	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	N	N
Multidisciplinary teams (Y/N) [at least two disciplines	Y	Y	Y	[illegible]	Y	N	Y	Y	Y	[illegible]	Y	Y	Y	Y
Faculty assigned students to teams (Y/N)	Y	Y	Y	Y	N	N	N	Y	N	N	Y	N	Y	Y
Client: DoD (Y/N)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Client: industry (Y/N)	N	N	Y	N	N	Y	N	N	Y	Y	Y	Y	Y	N
DoD mentor (assigned) (Y/N)	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N
Other mentors - includes industry (Y/N)	Y	N	Y	Y	Y	Y	Y	N	N	N	Y	Y	Y	N
Additional SMEs [Not PIs or co-PIs] (Y/N)	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	N	Y	N
Established relationships with nearby DoD command	Y	Y	N	N	Y	Y	N	N	N	N	Y	N	Y	N
SE PhD/MS students used as advisors (Y/N)	N	Y	Y	N	Y	Y	N	Y	N	Y	Y	N	N	N
Design Reviews (Y/N)	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	N
Client and/or mentor came for design reviews (Y/N)	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N
Physical prototype (including software) (Y/N)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
Prototype completed (Y/N)	N	N	Y	Y	Y	N	Y	Y	Y	N	Y	Y	Y	N
PI/Co-PI publications (Y/N)	Y	Y	N	Y	Y	N	Y	N	Y	N	Y	Y	N	Y
PI/Co-PI conference presentations (Y/N)	N	Y	Y	Y	Y	N	Y	N	Y	N	N	Y	N	Y
Students presented at conference- can be SIEDS or o	Y	N	N	N	N	Y	Y	Y	N	N	Y	N	N	N
Students received awards (Y/N)	N	N	N	Y	N	N	Y	N	Y	Y	Y	N	N	N
ROTC involved (Y/N)	N	N	Y	N	Y	N	N	N	N	N	N	N	N	N
1 student team (Y/N)	Y	Y	N	N	N	N	N	N	N	N	N	N	Y	N
2-3 student teams (Y/N)	N	N	N	N	N	N	N	Y	N	N	Y	N	N	N
4-6 student teams (Y/N)	N	N	Y	Y	Y	Y	Y	N	Y	Y	N	Y	Y	Y
Two semesters: first semester lecture only (Y/N)	N	Y	Y	Y	Y	Y	ne semeste	N	N	Y	N	Y	N	Y
Undergraduates only (Y/N)	Y	N	N	Y	N	N	Y	Y	N	Y	Y	N	Y	Y
Graduates only (Y/N)	N	Y	N	N	N	Y	N	N	N	N	N	N	N	N
Mixed (Y/N)	N	N	Y	N	Y	N	N	N	Y	N	N	Y	N	N
Number of student teams	1	1	9	5	6	semester d	4	2	), with seve	4		teams of 4-5 stu	1	4
Number of students first semester/second semester	7	5/5	33/17	20/24	30	38/38	17	were from	24/19	15/37	17/16	29/16	4	16
Number of mentors - internal and external	7	Multiple	7	1	5	7	2	2	2	approx 2-3	Over 5	3	2	0
Number times external mentor came to university	1	Multiple	over 5 times	2	ultiple tim	unknown	2	2	3	5	ultiple tim	2	2	0
Number of clients	7	0	7	1	2	7	2	2	0	3	ultiple clie	2	2	0
Number times client came to university	1	0	5	2	3	unknown	2	2	0	3	4	mmunicated	2	0
Mentor and client performed the same roles (Y/N)	Y	N/A	Y	Y	N	N	Y	Y	N/A	Y	N	Y	Y	N/A
DoD Problem area/prototype	Solar Energy - portable system with smarty grid, battery	Unmanned Air Vehicle w/ hybrid-electric propulsion system	secure communication devices	Hybrid mail truck, sparkle propeller, solar concentrator, underwater hull inspector, flare tube modificatio	immersive training vest	improving PACOM response for HA/DR	PEAK - global communication, local situational awareness, hardened generator, water purification unit	multiple user motion capture; micro expression facial motion capture	green expeditionary housing	integrated security of wireless sensor networks;black box design;wireless sensor networks for perimeter	Rapid assessment of water quality after natural disasters;using electroactive polymers to	humanitarian assistance/disaster relief: solar powered field medical facility; manual power generator;	augmented reality/optics/immersive training	improving surge power capabilities; personnel tracking device; portable water purification; portable renewable sea-based power generation, storage &

(Systems Engineering Program typology adopted from Brown, D.E. & Scherer, W.T. (2000). "Comparison of Systems Engineering Programs in the United States." and Reviews, 30(2), 204-212.
In IEEE Transactions on Systems, Man, and Cybernetics: Part C: Applications

BIBLIOGRAPHY

Banerji, M., Capozzoli, M., McSweeney, L., & Sinha, D. (1999). Beyond kappa: A review of interrater agreement measures. *The Canadian Journal of Statistics , 27* (1), 3-23.

Brown, D., & Scherer, W. (2000). A comparison of Systems Engineering Programs in the United States. *IEEE Transactions on System, Man, and Cybernetics-Part C, Applications and Reviews , 30* (2), 204-212.

Chen, H., Cannon, D., Gabrio, J., Leifer, L., Toye, G., & Bailey, T. (2005). Using Wikis and Weblogs to support reflective learning in an introductory engineering design course. In InGero, & Lindemann (Ed.), *Human Behavior in Design'05, Key Centre of Design Computing and Cognition* (pp. 95-105). University of Sydney.

Commitee on Developments in the Science of Learning. (2000). How People Learn: Brain, Mind, Experience, and School. (J. Bransford, A. Brown, & R. Cocking, Eds.) Washington D.C.: National Academy Press.

Defense Acquisition University. (2011). *Defense Acquisition Guidebook.* Retrieved from https://acc.dau.mil/CommunityBrowser.aspx?id=350719

Defense Acquisition University. (2011). *SPRDE-SE/PSE Competency Model.* Retrieved from https://acc.dau.mil/CommunityBrowser.aspx?id=406181

Leydens, J., Moskval, B., & Pavelich, M. (2004). Qualitative methods used in the assessment of engineering education. *Journal of Engineering Education , 93* (1), 65-72.

McGrath, E., Ardis, M., Lowes, S., Lam, S., & Jurado, C. (2011). *Research on bulding education and workforce capacity in systems engineering.* Workshop Report, Systems Engineering Research Center, Arlington.

Nation I.S.P. (2004). A study of the most frequent word families in the British National Corpus. (P. Bogaards, & B. Laufer, Eds.) *Vocabulary in a Second Language: Selection, Acquisition and Testing* , 3-13.

Nation, I.S.P. (2006). How large a vocabulary is needed for reading and listening? *Canadian Modern Language Review , 63* (1), 59-82.

National Aeronautical Space Administration. (2007). *NASA Procedural Requirements 7123.1A.* Retrieved from http://nodis3.gsfc.nasa.gov/displayDir.cfm?Internal ID=N PR 7123 001A &page name=main

National Defense Industrial Association SE Division Task Group . (2006). *Top five SE issues within DoD and Defense Industry.*

National Defense Industrial Association SE Division. (2010, July). *Top SE Issues in DoD and Defense Industry .* Retrieved January 2011, from http://www.ndia.org/Divisions/Divisions/SystemsEngineering/Documents/Studies/Top%20SE%20SE%20Issues%202010%20Report%20v11%20FINAL.pdf

Rosato, D., Braverman, B., & Jeffries, A. (2009, November). The 50 best jobs in America. *Money Magazine* , pp. 88-96.

Sage, A. (2000). Systems Engineering Education. *IEEE Transactions on Systems, Man, and Cybernetics, Part C, Applications and Reviews , 30* (2), 164-174.

Sim, J., & Hew, K. (2010). The use of weblogs in higher education settings: a review of empirical research. *Educational Research Review , 5* (2), 151-163.

U.S. Government. (2011). *NASA Case Study-Launching the Vasa, GSCF-1007C-1, 1-6.* Retrieved from http://library.gsfc.nasa.gov/casestudies/public/GSCF-1007C-1-Vasa.pdf